

PATHWAYS TO EXPLORATION: A REVIEW OF THE FUTURE OF HUMAN SPACE EXPLORATION

HEARING BEFORE THE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY HOUSE OF REPRESENTATIVES ONE HUNDRED THIRTEENTH CONGRESS

SECOND SESSION

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**PATHWAYS TO EXPLORATION: A REVIEW OF
OF THE FUTURE OF HUMAN SPACE
EXPLORATION**

WEDNESDAY, JUNE 25, 2014

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Committee met, pursuant to call, at 10:03 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Lamar Smith [Chairman of the Committee] presiding.

LAMAR S. SMITH, Texas
CHAIRMAN

EDDIE BERNICE JOHNSON, Texas
RANKING MEMBER

Congress of the United States
House of Representatives

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

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***Pathways to Exploration: A Review of the Future of Human
Space Exploration***

Wednesday, June 25, 2014

10:00 a.m. to 12:00 p.m.

2318 Rayburn House Office Building

Witnesses

Governor Mitch Daniels, Report Co-Chair and President, Purdue University

*Dr. Jonathan Lunine, Report Co-Chair and Director, Cornell University's Center for
Radiophysics and Space Research*

**U.S. House of Representatives
Committee on Science, Space, and Technology**

Pathways to Exploration: A Review of the Future of Human Space Exploration

CHARTER

Wednesday, June 25, 2014
10:00 a.m. – 12:00 p.m.
2318 Rayburn House Office Building

Purpose

At 10:00 am on Wednesday, June 25, 2014, the Science, Space, and Technology Committee will hold a hearing *Pathways to Exploration: A Review of the Future of Human Space Exploration*. Section 204 of the NASA Authorization Act of 2010 required the agency to enter into a contract with the National Academies to review the future of human spaceflight.¹ In 2012, the National Research Council appointed an ad hoc Committee on Human Spaceflight co-chaired by Governor Daniels and Dr. Lunine. Today's hearing will review the conclusions and recommendations of the Committee's report *Pathways to Exploration—Rationales and Approaches for a U.S. Program of Human Space Exploration* released earlier this month.

The executive summary for the report is attached to this charter for reference. The full report of *Pathways to Exploration: Rationales and Approaches for a U.S. Program of Human Space Exploration* is available on the website for the National Academies of Science and located here: http://www.nap.edu/catalog.php?record_id=18801.

Witnesses

- **Governor Mitch Daniels** – Co-Chair of the Report and President, Purdue University
- **Dr. Jonathan Lunine** – Co-Chair of the Report and Director, Cornell University's Center for Radiophysics and Space Research

Background

After President Obama cancelled the Constellation program in 2010 and the Space Shuttle program ended in 2011, NASA's human exploration program has endured an extremely difficult transition. The NASA Authorization Act of 2010 provided some stability in policy and programmatic guidance for the agency during this time. However, as the Committee on Human Spaceflight noted in its report:

"The United States has publicly funded its human spaceflight program on a continuous basis for more than a half-century. Today the United States is the major partner in a massive orbital facility—the International Space Station (ISS)—that is a model for how U.S. leadership can engage nations through soft power and is becoming the focal point for the first tentative steps in commercial cargo and crewed orbital spaceflights. And yet, a national consensus on the long-term future of human spaceflight beyond our commitment to the ISS remains elusive."

¹ NASA Authorization Act of 2010 (P.L. 111-267): <http://www.gpo.gov/fdsys/pkg/PLAW-111publ267/pdf/PLAW-111publ267.pdf>

Chairman SMITH. The Committee on Science, Space, and Technology will come to order.

Welcome to today's hearing entitled "Pathways to Exploration: A Review of the Future of Human Space Exploration." I will recognize myself for an opening statement and then the Ranking Member, the gentlewoman from Texas.

At a fundamental level, space exploration—the mission of NASA—is about inspiration. This inspiration fuels our desire to push the boundaries of the possible and reach beyond our own pale blue dot.

When the President cancelled the Constellation program in 2010, our chance to explore beyond low-Earth orbit was significantly delayed. To the dismay of the American people, the Administration made it clear that human space exploration was not a priority.

The first human footsteps on the Moon are a distant memory. And with the retirement of the Space Shuttle, NASA now pays Russia \$70 million to transport an American astronaut to the International Space Station and back. There is a sense that America is falling behind, with our best days behind us. Today, America's finest spaceships and largest rockets are found in museums rather than on launch pads.

The President has proposed capturing an asteroid and tugging it into lunar orbit for human exploration. But NASA's own advisors said, "it was not considered to be a serious proposal." Space exploration experts have criticized this plan before our Committee. And former NASA officials have called into question its merits.

The Administration's continued focus on costly distractions is harmful to our space program and does not inspire future generations to go into innovative fields such as science and math. However, a distinguished panel of experts has concluded that a return to "extended surface operations on the Moon" would make significant contributions to landing people on Mars. The same has not been said for the Asteroid Retrieval Mission, which is a mission without a realistic budget, without a destination, and without a certain launch date.

The witnesses before us today represent decades of public policy work and scientific investigation. They co-chaired the Committee on Human Spaceflight that recently released a report entitled "Pathways to Exploration: Rationales and Approaches for a U.S. Program of Human Space Exploration." This report confirmed that NASA lacks a plan for human space exploration. The NASA Authorization Act, which recently passed the House, requires a detailed plan for how NASA will land humans on Mars. This report offers suggestions on the best way to reach that goal.

Meanwhile, the Obama Administration continues to advocate increasing climate change funding at NASA at the expense of other priorities such as space exploration. There are 18 federal agencies that fund climate change research, but only one does space exploration.

The future of America's exploration efforts lead to Mars. Just as the first steps on the Moon were by Americans, the first flag to fly on another planet in our solar system should be that of the United States.

Great nations do great things. President Kennedy's call to America wasn't just about reaching the Moon; it was a reminder that we are an exceptional nation. We must rekindle within NASA the fire that blazed the trail to the Moon.

[The prepared statement of Mr. Smith follows:]

PREPARED STATEMENT OF CHAIRMAN LAMAR S. SMITH

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Great nations do great things. President Kennedy's call to America wasn't just about reaching the moon, it was a reminder that we are an exceptional nation. We must rekindle within NASA the fire that blazed the trail to the moon.

Chairman SMITH. That concludes my opening statement.

And the gentlewoman from Texas, Ms. Johnson, is recognized for hers.

Ms. JOHNSON. Thank you very much, Mr. Chairman, and good morning to all.

I would like also to welcome our distinguished witnesses to today's hearing.

I make no secret of the fact that I consider National Aeronautics and Space Administration to be a critical national asset. NASA is a source of technological and scientific innovation, an inspiration to generations of young people, a catalyst for economic growth, and a very positive symbol of American preeminence worldwide, as well

as visible demonstration of our commitment to international cooperation and the peaceful uses of outer space. Simply put, NASA is about the future.

Now it is a fact that NASA's human spaceflight activities account for a significant share of the resources invested in NASA. We need to ensure that those resources are invested wisely. That is why this morning's hearing is so important.

At Congress' direction, the National Academies undertook a comprehensive review of the future of human space exploration in the United States. That review has been completed and it is now up to Congress and the Administration to decide what we will do in response to the findings and recommendations contained in its final report.

This is a report that does not mince words, and for that we should be very grateful. As I said when the report was first released, the National Academies has provided the Nation with an important wakeup call. Their conclusions are clear. We are not going to have a human space exploration program worthy of this great nation if we continue down the current path of failing to provide the resources needed to make real progress and failing to embrace a clear goal and pathway to achieving that goal.

As Members of Congress, the ball is in our court and we have choices to make. We can choose to continue to argue about which President or who in Congress is to blame for the current state of our human space exploration program, but I honestly hope that we won't. We are where we are and we can't change the past. Our focus needs to be on how we proceed from this point forward, and I hope that our witnesses can provide some useful counsel to us in that regard.

In addition, we can choose to continue to pretend that a business-as-usual approach to our human space exploration program will suffice, but I hope we won't do that either because the report we are reviewing today makes clear that business as usual is not a sustainable approach. Whatever resources we are able to invest need to be invested effectively and efficiently toward the attainment of a clearly articulated goal. We really can't afford to do otherwise.

Finally, the National Academies' panel makes clear that we don't have unlimited time to decide what kind of human space exploration program we want for the Nation. It may be tempting for some to say that we shouldn't invest necessary resources in space exploration until we first fix Medicare or Medicaid, eliminate the deficit, or address a host of other major policy issues that have been identified by Members at various times. It is tempting to use those issues as an excuse for inaction, but the National Academies makes a compelling case that we do not have that luxury if we want to maintain meaningful human space exploration capability in this nation, which I strongly believe we do. We should of course address those other issues but that should not prevent us from investing in our future in the meantime.

And make no mistake about it, our Nation's human space exploration program with an ultimate goal of landing humans on Mars is about our future and that of our children and grandchildren. Mr. Chairman, the National Academies has done a great service by un-

dertaking the study that we will be hearing about today. I hope that this morning's hearing will be the first step in achieving a revitalized and focused exploration program for America. I want to work with my colleagues on both sides of the aisle to do just that.

In closing, I again want to welcome our witnesses and I yield back the balance of my time.

[The prepared statement of Ms. Johnson follows:]

PREPARED STATEMENT OF RANKING MEMBER EDDIE BERNICE JOHNSON

Good morning. I want to join the Chairman in welcoming our two distinguished witnesses to today's hearing.

I make no secret of the fact that I consider the National Aeronautics and Space Administration to be a critical national asset. NASA is a source of technological and scientific innovation, an inspiration to generations of young people, a catalyst for economic growth, and a very positive symbol of American preeminence worldwide as well as a visible demonstration of our commitment to international cooperation in the peaceful uses of outer space. Simply put, NASA is about the future.

Now it is a fact that NASA's human spaceflight activities account for a significant share of the resources invested in NASA. We need to ensure that those resources are invested wisely. That is why this morning's hearing is so important. At Congress's direction, the National Academies undertook a comprehensive review of the future of human space exploration in the United States. That review has been completed, and it is now up to Congress and the Administration to decide what we will do in response to the findings and recommendations contained in its final report.

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As Members of Congress, the ball is now in our court, and we have choices to make. We can choose to continue to argue about which President or who in Congress is to blame for the current state of our human space exploration program, but I earnestly hope that we won't. We are where we are, and we can't change the past. Our focus needs to be on how we proceed from this point forward, and I hope that our witnesses can provide some useful counsel to us in that regard.

In addition, we can choose to continue to pretend that a "business-as-usual" approach to our human space exploration program will suffice, but I hope we won't do that either. Because the report we are reviewing today makes clear that "business-as-usual" is not a sustainable approach. Whatever resources we are able to invest need to be invested effectively and efficiently towards the attainment of a clearly articulated goal. We really can't afford to do otherwise.

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We should of course address those other issues, but that should not prevent us from investing in our future in the meantime. And make no mistake about it—our nation's human space exploration program, with an ultimate goal of landing humans on Mars, is about our future and that of our children and grandchildren.

Mr. Chairman, the National Academies has done us a great service by undertaking the study that we will be hearing about today. I hope that this morning's hearing will be the first step in achieving a revitalized and focused space exploration program for America, and I want to work with my colleagues on both sides of the aisle to do just that.

In closing, I again want to welcome our witnesses, and I yield back the balance of my time.

Chairman SMITH. Thank you, Ms. Johnson.

We will now proceed to introduce the witnesses. And to introduce our first witness, I will recognize the gentleman from Indiana, Dr. Bucshon.

Mr. BUCSHON. Thank you, Mr. Chairman.

Our first witness is Governor Mitch Daniels, the President of Purdue University, which has graduated 23 astronauts, including Neil Armstrong. Prior to this appointment, he served two terms as the 49th Governor of my home State of Indiana. He also served as Chief of Staff to Senator Richard Lugar, Senior Advisor to President Ronald Reagan, and Director of the Office of Management and Budget under President George W. Bush.

In addition to his strong record of public service, he has served as a Senior Executive at Eli Lilly based in Indianapolis, among other positions he has held.

President Daniels earned his bachelor's degree from the Woodrow Wilson School of Public and International Affairs at Princeton and his J.D. from Georgetown University Law Center.

Welcome, Governor Daniels.

Chairman SMITH. Thank you, Dr. Bucshon. I will introduce our second witness, who is Dr. Jonathan Lunine, the Director of the Center for Radiophysics and Space Research and the David C. Duncan Professor in the Physical Sciences at Cornell University. He is co-investigator of the Juno Mission to Jupiter and an interdisciplinary scientist for the James Webb Space Telescope. Dr. Lunine has shared and served on committees for NASA and the National Science Foundation. He also is a member of the National Academy of Sciences and a Fellow of the American Geophysical Union and American Association for the Advancement of Science.

Dr. Lunine received his bachelor's in physics and astronomy from the University of Rochester and his master's and Ph.D. in planetary science from the California Institute of Technology.

We welcome you both today. It is nice to have two experts on the subject present.

And, Governor Daniels, we will begin with you.

**TESTIMONY OF GOVERNOR MITCH DANIELS,
REPORT CO-CHAIR AND PRESIDENT,
PURDUE UNIVERSITY**

Gov. DANIELS. Mr. Chairman, Ranking Member Johnson, and Members of the Committee, we thank you for this opportunity to be here on behalf of our Committee on Human Spaceflight established in response to the NASA Authorization Act of 2010. That act called on NASA to ask the National Academies to review the goals, core capabilities, and direction of our nation's human spaceflight program. And we released our report on June 5. Dr. Lunine and I are here to summarize it for you.

As envisioned in the 2010 act, the Committee membership was very diverse, composed not solely or even mostly of experts from the human spaceflight community, but instead had members from fields as diverse as planetary science, astronomy, political science and history, sociology, public opinion and polling, economics, human spaceflight experience, international peace and security, and others.

All of us came into this process with open minds and brought to the work our divergent points of view. In the end we came to the strong consensus that there is a convincing case to be made for a continuation of our nation's human spaceflight program, provided that the pathways approach and decision rules recommended in our report are adopted.

We did so because we became convinced only after lengthy discussion and analysis that a combination of what we labeled the pragmatic and aspirational rationales, including the human impulse to explore and search for new knowledge in places we have never been, justifies the cost, the risk and the opportunities associated with sending humans beyond low-Earth orbit, and especially for the "horizon goal" we identify as Mars.

Getting humans to the surface of Mars will be a daunting challenge. It is immensely difficult, probably more so than most laymen and even many experts have recognized. Succeeding in this endeavor will require, we believe, a very different way of doing business than the Nation has been practicing in recent decades, particularly as it is likely to take 30 years or more to reach the goal.

As its highest priority recommendation, the committee recommends what we call a "pathways approach," requiring the government to come to a consensus on achieving a highly disciplined set of objectives from which the Nation would not deviate over time. A pathway in this scenario would involve a predefined set of chosen destinations and milestones, each of which would generate technical and engineering requirements which, as much as possible, would feed forward into the next goal and eventually the horizon goal.

The committee does not recommend any specific pathway—that is for you and for future leadership—but we do note in our report that any pathway that could successfully land humans on the surface of Mars would require funding above constant dollars.

Pursuing unwaveringly the consensus choice of a pathway over the term of multiple decades and the sustained support of the advances required by the resulting exploration architecture are the keys to a sustainable approach to human spaceflight.

Mr. Chairman, I can't stress enough how critical it is the Nation take a new approach different from the recent way of doing business in space. Work needs to begin soon on the most difficult and mission-critical technical challenges of any pathway to Mars, and out of many such challenges, our committee singles out Mars entry, descent and landing; in-space propulsion and power; and radiation safety for very special emphasis.

In addition, we are in total agreement that achieving the goal of a human presence on Mars will require the United States to expand its partnerships with other space faring nations, including an openness to working with China, with whatever safeguards might have to be put in place. Such international partnerships should include much greater cost-sharing than our partners have provided up to now, and that can only happen if those partners are given the responsibility to provide substantial elements to the overall architecture, which they will help design and build.

Finally, Mr. Chairman, we ask that readers of our report recognize that the risks of human spaceflight, including the risks to

human life, are high, and setbacks are inevitable. Lives are likely to be lost in pursuit of such a tremendous endeavor, and governing statutes will need to recognize that grim fact. And while we recognize that many of our recommendations will be seen by many as unrealistic or perhaps even naive, we would observe that, absent changes along the lines we are recommending, the goal of reaching Mars in any meaningful time frame is itself unrealistic.

Our committee hopes that that our report will carry the national conversation forward in the direction of realism, realism about public opinion, about risk, about cost, and about the incredibly daunting technical challenges of the horizon goal we hope the world embraces. And most of all, we hope to foster greater realism about the fact that if we really do want to go to Mars, then many actors, public and private, need to change long-standing behaviors and expectations. We are optimistic the public will support a consensus national goal and we believe the rationales justify its pursuit. We believe the achievement would be monumental if it occurred, but we think there is really one and possibly only one approach to get there, and we have offered up our best ideas in support of that approach.

[The prepared statement of Gov. Daniels follows:]

Testimony of

Governor Mitch Daniels
President of Purdue University
and
Professor Jonathan Lunine, Ph.D.
David C. Duncan Professor in the Physical Sciences
Cornell University

Co-Chairs, Committee on Human Spaceflight
Division on Engineering and Physical Sciences
National Research Council
The National Academies

before the

Committee on Science, Space, and Technology
U.S. House of Representatives

June 25, 2014

[Governor Daniels begins]

Mr. Chairman, Ranking Member Johnson, members of the committee:

Thank you for the opportunity to speak to you today on issues concerning the nation's human spaceflight program. Today my co-chair Jonathan Lunine and I are here to represent the National Research Council's Committee on Human Spaceflight, established in response to the NASA Authorization Act of 2010. That act called on NASA to ask the National Academies to review the goals, core capabilities, and direction of our nation's human spaceflight program. After about 18 months of work we released our report on June 5th and Dr. Lunine and I are here today to briefly summarize its contents. The executive summary of that report which you have before you contains a lot more detail than we might cover today. And indeed I would urge interested members to read Chapter 1 of our report, which contains all our detailed findings and recommendations.

As envisioned in the 2010 Act, the background of our committee's membership was very diverse. This committee was not composed solely or even mostly of experts from the human spaceflight community—as might have been the case with other major reports on this topic in the past—but instead had members from fields as diverse as planetary science, astronomy, political science and history, sociology, public opinion and polling, economics, human spaceflight experience, international peace and security, and so on. Although all of us came into this process with open minds and brought to the work divergent points of view, in the end we came to the strong consensus that there is a convincing case to be made for a continuation of our nation's human spaceflight program, provided that the pathways approach and decision rules recommended in our report are adopted.

Why did we come to that position? We did so because we became convinced through lengthy discussion and analysis that a combination of what we call the pragmatic and aspirational rationales, including the human impulse to explore and search for new knowledge in places we have never been, justifies the cost, risk and opportunities associated with sending humans beyond low Earth orbit—especially toward the “horizon goal” we identified as Mars.

Getting humans to the surface of Mars will be a daunting challenge. It is immensely difficult, probably more so than most laymen and even many experts have recognized. Succeeding in this endeavor will require a very different way of doing business than the nation has been practicing in recent decades, particularly as it is likely to take thirty years or more for us to reach our goal.

With this challenge in mind, as its highest priority recommendation, the committee recommends what we call a “pathways approach”, which would require the government to come to a consensus on achieving a highly disciplined set of objectives from which the nation would not deviate over time. A pathway in this scenario would involve a pre-defined set of chosen destinations and milestones—stepping stones if you will—each of which would generate technical and engineering requirements which, as much as possible, would feed

forward toward the next step and eventually the horizon goal. The committee does not recommend any specific pathway, but we do note in our report that any pathway that could successfully land humans on the surface of Mars would require funding above constant dollars. Pursuing unwaveringly the consensus choice of a pathway over the long term of multiple decades and the sustained support of the technical advances required by the resulting exploration architecture are the keys to unlocking a sustainable approach to human spaceflight for our nation.

Mr. Chairman, I cannot stress enough how critical it is that this nation takes a new approach that goes beyond the recent way of doing business in space. We need to come to a consensus on the pathway of choice if we are going to decide to continue to pursue human exploration beyond low Earth orbit. Work needs to begin soon on the most difficult and mission-critical technical challenges of any pathway to Mars: out of many such challenges, we single out Mars entry, descent and landing; in-space propulsion and power; and radiation safety for special emphasis. In addition we were in total agreement that achieving the goal of a human presence on Mars will require the U.S. to expand its partnerships with other spacefaring nations, including an openness to working with China with whatever safeguards we might have to put in place. Such international partnerships should include much greater cost-sharing than our partners have provided up to now, but that can only happen if those partners are given the responsibility to provide substantive and substantial elements to the overall architecture, which they will help design and build. Indeed our committee's report clearly states that our human spaceflight program should engage with any partner—governmental or commercial—that can help solve technical and programmatic impediments to pathway progress.

Finally, Mr. Chairman, Ms. Johnson, members of the Committee, before I hand over to my colleague and friend Dr. Lunine, I want to stress here to you, to all our elected representatives and leaders, and to the public, that we all need to recognize that the risks of human spaceflight, including the risks to human life, are high, and setbacks are inevitable. Lives are likely to be lost in pursuit of such a tremendous endeavor, and governing statutes will need to recognize that grim fact. And while we recognize that many of our recommendations will be seen by many as “unrealistic” or perhaps even naive, we would observe that, absent changes along the lines we are recommending, the goal of reaching Mars on any meaningful time frame is itself unrealistic.

Mr. Chairman, it is my personal hope that that our report will carry the national conversation forward in the direction of realism: realism about public opinion, about risk, about cost, and about the incredibly daunting technical challenges of the horizon goal that we believe the world embraces. Most of all, we hope to foster greater realism about the fact that if we really do want to go to Mars then many actors public and private need to change long-standing behaviors and expectations. We are optimistic the public will support a consensus national goal and we believe the rationales justify its pursuit. We believe the achievement would be monumental if it occurred, but we think there is really one and possibly only one approach to get there, and we've offered up ideas in support of that approach in this report.

[Dr. Lunine continues]

As Governor Daniels noted, we would urge members and others to consider—if you cannot read the entire document—to read Chapter 1 of our report, where you will find our major findings and recommendations on issues such as: public and stakeholder opinions about space exploration and human spaceflight in particular; an honest and detailed independent analysis of the technical and affordability realities associated with three possible exploration pathways that lead to Mars; an examination of the rationales for human spaceflight; and most importantly our recommendations on adopting the “pathways approach” we believe will help our nation achieve that next giant leap for humankind.

Let me turn quickly to some of those issues, and Governor Daniels and I would be more than happy to answer any questions members may have following this statement.

Firstly, anyone who reads about the history of space will come quickly to realize that there are many myths that surround both public opinion about human spaceflight, and the proven benefits from human spaceflight. What the committee found was that, if a decision to continue a U.S. human space exploration program were to be based simply on the interests and priorities expressed in public opinion polls taken over the past few decades, it is likely we would not have gone to space. If the decision were based simply on the available data on *proven* benefits that uniquely accrue from a human space exploration, then we would likely not go. However, while the committee felt it was important to examine as closely as possible both public opinion and the historic rationales—and in fact it was charged to do so—we were also aware that such data have numerous limitations and interpretations. We also recognized that by these kinds of criteria alone, we would never have stepped foot on the Moon, yet that achievement is now viewed as a source of inspiration and great pride by Americans.

In fact, Mr. Chairman, it has been leadership at the national level, at a political level, that determines whether our nation will pursue major new ventures. Our elected leaders have shown courage and vision in the pursuit of human endeavor in space and when those visions are implemented—such as with the Apollo program or the Shuttle program—the public is supportive of our government having spent our tax dollars on what are viewed as endeavors of national importance.

In the end it was the judgment of this diverse committee that the more aspirational rationales, when supplemented by the practical benefits associated with the more pragmatic rationales, do argue for a continuation of the nation’s human spaceflight program, provided that certain conditions are met. It is not, however, this committee’s opinion that is relevant on this issue. Whether to pursue human exploration beyond low Earth orbit in a truly sustainable way is a decision that deserves careful consideration by our nation’s leaders, stakeholders both favorable and opposed, and the public at large. And in making that decision it will be important to ask a question posed many times by us to those provided input to this study, “What would a future be like where there was no expectation that Americans will go into space?”

But as such decisions are contemplated, and as Governor Daniels mentioned, we cannot ignore the significant leaps in technical capability that will be required to land and sustain humans on Mars. Achieving those leaps was the motivation behind our recommended pathways approach since only a sustained program that builds upon a sequence of technical and exploration successes can buy down the risk involved in getting to Mars in any reasonable timeframe. As an example, in one of the possible pathways analyzed in detail in the report, one of the goals or milestones was extended human operations on the lunar surface. I stress extended surface operations—not merely a repeat of an Apollo type landing. Why was this included? Because our technical panel realized—and the committee concurred—that extended surface operations on the Moon would make significant contributions to a strategy ultimately aimed at landing people on Mars by allowing for the development and testing of key operational technologies.

Mr. Chairman, Mars is incredibly hard.

Completing any of the pathways described in our report or indeed any other pathway that is likely to succeed, requires the development of a number of mission elements and technological capabilities and a budgetary support that exceeds growth in purchasing power. The report identifies 10 high-priority capabilities that should be addressed by current research and development activities, with a particular emphasis on Mars entry, descent, and landing, radiation safety, and in-space propulsion and power. These three capabilities will be the most difficult to develop in terms of costs, schedule, technical challenges, and gaps between current and needed abilities. And because the challenges are so great our committee came to the conclusion that our human spaceflight program sits at an important juncture. If there is any significant delay in the United States making a commitment to a truly sustainable program of human spaceflight beyond LEO, we risk a long gap in U.S. human spaceflight activity following the decommissioning of the International Space Station—just as the termination of the Space Shuttle led to a hiatus in U.S. capability to launch astronauts into space. The nation needs to decide now whether it will choose to support a sustained national and international endeavor to pursue exploration beyond low Earth orbit.

If the nation does decide to undertake one of the greatest of human technical endeavors it has ever attempted, we have provided in our report what we call Pathway Principles that could help in the choice of a consensus pathway to that goal. In addition we provide a set of decision rules—guidelines on how to manage the pursuit of the chosen pathway when stressors such as diminished budgets or indeed larger than expected budgets might arise.

Mr Chairman, our committee is convinced that these principles and decision rules provide a way for our national leadership to decide on a given pathway, measure progress in its pursuit, navigate moving off one pathway to another, or cease the endeavor altogether.

A key element of those principles is that a pathway's chosen set of destinations and stepping stones would generate technical and engineering requirements which as much as possible would feed forward toward the next step and eventually the horizon goal. The committee does not recommend any specific pathway—we were not charged to do so. But we do feel strongly

that given the cost of human exploration and the potential cost in human life, only a human presence on another world can justify its pursuit and as we have said previously, Mars is humanity's horizon goal.

To reach that horizon goal will require decades of sustained effort and hundreds of billions of dollars to accomplish. To be a sustainable program, it will require a steadfast national commitment to a consensus goal, international collaboration, and a budget that increases by more than the rate of inflation.

Mr. Chairman, Ms. Johnson, members of the Committee: We are not the first to say that our nation's commitment to human exploration cannot change direction election after election. But in the end our elected leaders are not the impediment to achieving great goals in space, you are the critical enablers of our nation's investment in human spaceflight. Only you can ensure that the leadership, personnel, governance, and resources are in place that will assure human beings will one day walk on the red soil of Mars.

Thank you again for the opportunity to testify today and we remain at your disposal for questions.

MITCHELL E. DANIELS, JR.
PRESIDENT, PURDUE UNIVERSITY
JUNE 2014

MITCHELL E. DANIELS, Jr. is the president of Purdue University. Immediately prior to this appointment, he served two terms as the 49th Governor of the State of Indiana. As the leader of the Hoosier state, he led a host of reforms aimed at strengthening the Indiana economy and improving the ethical standards, fiscal condition and performance of state government. Previously, he has been the CEO of the Hudson Institute and president of Eli Lilly and Company's North America Pharmaceutical Operations. In the political arena, he also served as chief of staff to Senator Richard Lugar, senior advisor to President Ronald Reagan and director of the Office of Management and Budget under President George W. Bush (January 2001 to June 2003).

He is the author of the book *Keeping the Republic: Saving America by Trusting Americans*. Mr. Daniels earned his B.S. from the Woodrow Wilson School of Public and International Affairs at Princeton University and his J.D. from the Georgetown University Law Center.

Chairman SMITH. Thank you, Governor Daniels.
And, Dr. Lunine.

**TESTIMONY OF DR. JONATHAN LUNINE,
REPORT CO-CHAIR AND DIRECTOR,
CORNELL UNIVERSITY'S CENTER FOR
RADIOPHYSICS AND SPACE RESEARCH**

Dr. LUNINE. Mr. Chairman, Ranking Member Johnson, Members, let me add my thanks to you all for giving us the opportunity to talk about this report this morning.

We recognize it is a very long report with a lot of detail, and so if you cannot or have not read the entire document, certainly Chapter 1 is the important chapter to read. And in particular there you will find our major findings and recommendations on issues such as public and stakeholder opinions about space exploration and human spaceflight in general; an honest and detailed independent analysis of the technical and affordability realities associated with the three example exploration pathways that we have put together that lead to Mars; an examination of the rationales for human spaceflight; and most importantly, our recommendation on adopting what we call the "pathways approach" that we believe will help our Nation achieve that next giant leap for humankind.

Anybody who reads about the history of space will come to realize very quickly that there are many myths that surround both public opinion and proven benefits from human spaceflight. If the decision to pursue human spaceflight were based simply on the available data on proven benefits that uniquely accrue from this endeavor or were based on public opinion being in the majority supporting a particular program in advance, then we would likely not go. We also recognize that by these kinds of criteria, Americans would never have set foot on the Moon, and yet that achievement is now viewed as a source of inspiration and great pride by many, if not most, Americans.

In fact, Mr. Chairman, it has been political leadership that determines whether our nation will pursue major new ventures. Our elected leaders have shown courage and vision in the pursuit of human endeavors in space, and when those visions are implemented—such as with Apollo or the Shuttle—the public is retrospectively supportive of the expenditures of our tax dollars on what are viewed as endeavors of national importance.

In the end it was the judgment of this diverse committee that the aggregate of the aspirational and pragmatic rationales does argue for a continuation of the Nation's human spaceflight program. In effect, the whole was greater than the sum of the parts. Whether to pursue human exploration beyond low-Earth orbit in a truly sustainable way is a decision that deserves careful consideration by our Nation's leaders, stakeholders, and the public at large. And in making that decision it will be paramount to ask the question, "What would a future be like where there were no expectation that Americans would once again venture into space?"

But as such decisions are contemplated, we cannot ignore the significant leaps in technical capability that will be required to land and sustain humans on Mars. Governor Daniels has talked about some of those key technologies. And these will be extremely

difficult to develop in terms of cost, schedule, technical challenges, and gaps between current and needed capabilities. Achieving these leaps was the motivation behind our recommendation of adopting a pathways approach, since only a sustained program that builds upon a sequence of technical and exploration successes can buy down the risk involved in getting to Mars in a reasonable time frame.

In one of the possible pathways analyzed in detail in the report—and these are example pathways—we included as a stepping stone extended human operations on the lunar surface. Our technical panel concluded, and the committee concurred, that extended surface operations on the Moon, not Apollo-style sorties, but extended surface operations would make significant contributions to reaching the horizon goal through development and testing of key operational technologies.

Mr. Chairman, Mars really is incredibly hard. And to reach that horizon goal will cost decades, hundreds of billions of dollars, and human lives. To be a sustainable program, it will require a steadfast national commitment to a consensus goal, international collaboration, and a budget that increases by more than the rate of inflation.

If the Nation does decide to undertake one of the greatest of human technical endeavors it has ever attempted, and we assert that there is not much time in which to make this decision, we have provided in our report what we call the Pathways Principles that will help in the choice of a consensus pathway to that goal and decision rules that will serve as guidelines on how to manage the pursuit of the chosen pathway when stressors such as diminished budgets might arise.

Our committee is convinced that these principles and decision rules provide a way for our national leadership to decide on a given pathway, measure progress in its pursuit, navigate off one pathway to another, or cease the endeavor altogether.

But in the end, it is our elected leaders who will be the critical enablers of our nation's investment in human spaceflight that ultimately one day may put American astronauts on the red soil of Mars.

Thank you again for the opportunity to testify today on this critical national question.

[The prepared statement of Dr. Lunine follows:]

Testimony of

Governor Mitch Daniels
President of Purdue University
and
Professor Jonathan Lunine, Ph.D.
David C. Duncan Professor in the Physical Sciences
Cornell University

Co-Chairs, Committee on Human Spaceflight
Division on Engineering and Physical Sciences
National Research Council
The National Academies

before the

Committee on Science, Space, and Technology
U.S. House of Representatives

June 25, 2014

[Governor Daniels begins]

Mr. Chairman, Ranking Member Johnson, members of the committee:

Thank you for the opportunity to speak to you today on issues concerning the nation's human spaceflight program. Today my co-chair Jonathan Lunine and I are here to represent the National Research Council's Committee on Human Spaceflight, established in response to the NASA Authorization Act of 2010. That act called on NASA to ask the National Academies to review the goals, core capabilities, and direction of our nation's human spaceflight program. After about 18 months of work we released our report on June 5th and Dr. Lunine and I are here today to briefly summarize its contents. The executive summary of that report which you have before you contains a lot more detail than we might cover today. And indeed I would urge interested members to read Chapter 1 of our report, which contains all our detailed findings and recommendations.

As envisioned in the 2010 Act, the background of our committee's membership was very diverse. This committee was not composed solely or even mostly of experts from the human spaceflight community—as might have been the case with other major reports on this topic in the past—but instead had members from fields as diverse as planetary science, astronomy, political science and history, sociology, public opinion and polling, economics, human spaceflight experience, international peace and security, and so on. Although all of us came into this process with open minds and brought to the work divergent points of view, in the end we came to the strong consensus that there is a convincing case to be made for a continuation of our nation's human spaceflight program, provided that the pathways approach and decision rules recommended in our report are adopted.

Why did we come to that position? We did so because we became convinced through lengthy discussion and analysis that a combination of what we call the pragmatic and aspirational rationales, including the human impulse to explore and search for new knowledge in places we have never been, justifies the cost, risk and opportunities associated with sending humans beyond low Earth orbit—especially toward the “horizon goal” we identified as Mars.

Getting humans to the surface of Mars will be a daunting challenge. It is immensely difficult, probably more so than most laymen and even many experts have recognized. Succeeding in this endeavor will require a very different way of doing business than the nation has been practicing in recent decades, particularly as it is likely to take thirty years or more for us to reach our goal.

With this challenge in mind, as its highest priority recommendation, the committee recommends what we call a “pathways approach”, which would require the government to come to a consensus on achieving a highly disciplined set of objectives from which the nation would not deviate over time. A pathway in this scenario would involve a pre-defined set of chosen destinations and milestones—stepping stones if you will—each of which would generate technical and engineering requirements which, as much as possible, would feed

forward toward the next step and eventually the horizon goal. The committee does not recommend any specific pathway, but we do note in our report that any pathway that could successfully land humans on the surface of Mars would require funding above constant dollars. Pursuing unwaveringly the consensus choice of a pathway over the long term of multiple decades and the sustained support of the technical advances required by the resulting exploration architecture are the keys to unlocking a sustainable approach to human spaceflight for our nation.

Mr. Chairman, I cannot stress enough how critical it is that this nation takes a new approach that goes beyond the recent way of doing business in space. We need to come to a consensus on the pathway of choice if we are going to decide to continue to pursue human exploration beyond low Earth orbit. Work needs to begin soon on the most difficult and mission-critical technical challenges of any pathway to Mars: out of many such challenges, we single out Mars entry, descent and landing; in-space propulsion and power; and radiation safety for special emphasis. In addition we were in total agreement that achieving the goal of a human presence on Mars will require the U.S. to expand its partnerships with other spacefaring nations, including an openness to working with China with whatever safeguards we might have to put in place. Such international partnerships should include much greater cost-sharing than our partners have provided up to now, but that can only happen if those partners are given the responsibility to provide substantive and substantial elements to the overall architecture, which they will help design and build. Indeed our committee's report clearly states that our human spaceflight program should engage with any partner—governmental or commercial—that can help solve technical and programmatic impediments to pathway progress.

Finally, Mr. Chairman, Ms. Johnson, members of the Committee, before I hand over to my colleague and friend Dr. Lunine, I want to stress here to you, to all our elected representatives and leaders, and to the public, that we all need to recognize that the risks of human spaceflight, including the risks to human life, are high, and setbacks are inevitable. Lives are likely to be lost in pursuit of such a tremendous endeavor, and governing statutes will need to recognize that grim fact. And while we recognize that many of our recommendations will be seen by many as “unrealistic” or perhaps even naive, we would observe that, absent changes along the lines we are recommending, the goal of reaching Mars on any meaningful time frame is itself unrealistic.

Mr. Chairman, it is my personal hope that that our report will carry the national conversation forward in the direction of realism: realism about public opinion, about risk, about cost, and about the incredibly daunting technical challenges of the horizon goal that we believe the world embraces. Most of all, we hope to foster greater realism about the fact that if we really do want to go to Mars then many actors public and private need to change long-standing behaviors and expectations. We are optimistic the public will support a consensus national goal and we believe the rationales justify its pursuit. We believe the achievement would be monumental if it occurred, but we think there is really one and possibly only one approach to get there, and we've offered up ideas in support of that approach in this report.

[Dr. Lunine continues]

As Governor Daniels noted, we would urge members and others to consider—if you cannot read the entire document—to read Chapter 1 of our report, where you will find our major findings and recommendations on issues such as: public and stakeholder opinions about space exploration and human spaceflight in particular; an honest and detailed independent analysis of the technical and affordability realities associated with three possible exploration pathways that lead to Mars; an examination of the rationales for human spaceflight; and most importantly our recommendations on adopting the “pathways approach” we believe will help our nation achieve that next giant leap for humankind.

Let me turn quickly to some of those issues, and Governor Daniels and I would be more than happy to answer any questions members may have following this statement.

Firstly, anyone who reads about the history of space will come quickly to realize that there are many myths that surround both public opinion about human spaceflight, and the proven benefits from human spaceflight. What the committee found was that, if a decision to continue a U.S. human space exploration program were to be based simply on the interests and priorities expressed in public opinion polls taken over the past few decades, it is likely we would not have gone to space. If the decision were based simply on the available data on *proven* benefits that uniquely accrue from a human space exploration, then we would likely not go. However, while the committee felt it was important to examine as closely as possible both public opinion and the historic rationales—and in fact it was charged to do so—we were also aware that such data have numerous limitations and interpretations. We also recognized that by these kinds of criteria alone, we would never have stepped foot on the Moon, yet that achievement is now viewed as a source of inspiration and great pride by Americans.

In fact, Mr. Chairman, it has been leadership at the national level, at a political level, that determines whether our nation will pursue major new ventures. Our elected leaders have shown courage and vision in the pursuit of human endeavor in space and when those visions are implemented—such as with the Apollo program or the Shuttle program—the public is supportive of our government having spent our tax dollars on what are viewed as endeavors of national importance.

In the end it was the judgment of this diverse committee that the more aspirational rationales, when supplemented by the practical benefits associated with the more pragmatic rationales, do argue for a continuation of the nation’s human spaceflight program, provided that certain conditions are met. It is not, however, this committee’s opinion that is relevant on this issue. Whether to pursue human exploration beyond low Earth orbit in a truly sustainable way is a decision that deserves careful consideration by our nation’s leaders, stakeholders both favorable and opposed, and the public at large. And in making that decision it will be important to ask a question posed many times by us to those provided input to this study, “What would a future be like where there was no expectation that Americans will go into space?”

But as such decisions are contemplated, and as Governor Daniels mentioned, we cannot ignore the significant leaps in technical capability that will be required to land and sustain humans on Mars. Achieving those leaps was the motivation behind our recommended pathways approach since only a sustained program that builds upon a sequence of technical and exploration successes can buy down the risk involved in getting to Mars in any reasonable timeframe. As an example, in one of the possible pathways analyzed in detail in the report, one of the goals or milestones was extended human operations on the lunar surface. I stress extended surface operations—not merely a repeat of an Apollo type landing. Why was this included? Because our technical panel realized—and the committee concurred—that extended surface operations on the Moon would make significant contributions to a strategy ultimately aimed at landing people on Mars by allowing for the development and testing of key operational technologies.

Mr. Chairman, Mars is incredibly hard.

Completing any of the pathways described in our report or indeed any other pathway that is likely to succeed, requires the development of a number of mission elements and technological capabilities and a budgetary support that exceeds growth in purchasing power. The report identifies 10 high-priority capabilities that should be addressed by current research and development activities, with a particular emphasis on Mars entry, descent, and landing, radiation safety, and in-space propulsion and power. These three capabilities will be the most difficult to develop in terms of costs, schedule, technical challenges, and gaps between current and needed abilities. And because the challenges are so great our committee came to the conclusion that our human spaceflight program sits at an important juncture. If there is any significant delay in the United States making a commitment to a truly sustainable program of human spaceflight beyond LEO, we risk a long gap in U.S. human spaceflight activity following the decommissioning of the International Space Station—just as the termination of the Space Shuttle led to a hiatus in U.S. capability to launch astronauts into space. The nation needs to decide now whether it will choose to support a sustained national and international endeavor to pursue exploration beyond low Earth orbit.

If the nation does decide to undertake one of the greatest of human technical endeavors it has ever attempted, we have provided in our report what we call Pathway Principles that could help in the choice of a consensus pathway to that goal. In addition we provide a set of decision rules—guidelines on how to manage the pursuit of the chosen pathway when stressors such as diminished budgets or indeed larger than expected budgets might arise.

Mr Chairman, our committee is convinced that these principles and decision rules provide a way for our national leadership to decide on a given pathway, measure progress in its pursuit, navigate moving off one pathway to another, or cease the endeavor altogether.

A key element of those principles is that a pathway's chosen set of destinations and stepping stones would generate technical and engineering requirements which as much as possible would feed forward toward the next step and eventually the horizon goal. The committee does not recommend any specific pathway—we were not charged to do so. But we do feel strongly

that given the cost of human exploration and the potential cost in human life, only a human presence on another world can justify its pursuit and as we have said previously, Mars is humanity's horizon goal.

To reach that horizon goal will require decades of sustained effort and hundreds of billions of dollars to accomplish. To be a sustainable program, it will require a steadfast national commitment to a consensus goal, international collaboration, and a budget that increases by more than the rate of inflation.

Mr. Chairman, Ms. Johnson, members of the Committee: We are not the first to say that our nation's commitment to human exploration cannot change direction election after election. But in the end our elected leaders are not the impediment to achieving great goals in space, you are the critical enablers of our nation's investment in human spaceflight. Only you can ensure that the leadership, personnel, governance, and resources are in place that will assure human beings will one day walk on the red soil of Mars.

Thank you again for the opportunity to testify today and we remain at your disposal for questions.

JONATHAN I. LUNINE, *Co-Chair*, is the director of the Center for Radiophysics and Space Research and the David C. Duncan Professor in the Physical Sciences at Cornell University. Dr. Lunine is interested in how planets form and evolve, what processes maintain and establish habitability, and what the limits of environments capable of sustaining life are. He pursues these interests through theoretical modeling and participation in spacecraft missions. He works with the radar and other instruments on the Cassini Saturn Orbiter and was part of the science team for the Huygens landing on Saturn's moon Titan. He is co-investigator on the Juno mission to Jupiter, launched in 2011, and an interdisciplinary scientist for the James Webb Space Telescope. Dr. Lunine has contributed to or led a variety of mission concept studies for solar system probes and space-based detection of planets around other stars. He has chaired or served on a number of advisory and strategic planning committees for NASA and the National Science Foundation (NSF). He is the winner of the Harold C. Urey Prize of the DPS/American Astronomical Society, the Macelwane Medal of the American Geophysical Union (AGU), the Zeldovich Prize in Commission B of Committee on Space Research (COSPAR), and the Basic Science Award of the International Academy of Astronautics. He is a member of the National Academy of Sciences (NAS) and a fellow of the AGU and American Association for the Advancement of Science (AAAS). Dr. Lunine received a B.S. in physics and astronomy from the University of Rochester and an M.S. and a Ph.D. in planetary science from the California Institute of Technology. Dr. Lunine has served on several National Research Council (NRC) committees, including as co-chair for the Committee on the Origins and Evolution of Life and the Committee for a Review of Programs to Determine the Extent of Life in the Universe, and as a member of the Committee on Decadal Survey on Astronomy and Astrophysics 2010.

Chairman SMITH. Thank you, Dr. Lunine. And I will recognize myself for questions.

One of the conclusions of your report is as follows: "To continue on the present course is to invite failure, disillusionment, and the loss of the long-standing international perception that human spaceflight is something the United States does best." That is an incredible summary of where we stand today and I don't know that too many people would disagree with it.

My first question, Governor Daniels, may I direct to you, and that is does the Obama Administration have a plan to get to Mars, as difficult and as costly as it might be?

And, Dr. Lunine, I hope it doesn't cost lives, but inevitably exploring new frontiers does.

But, Governor Daniels, does the Administration have a path, have a plan to get to Mars as we sit here today?

Gov. DANIELS. Mr. Chairman, I believe our committee's statements, the one that you read and others that we made, were meant to refer not to any one Administration but really to a persistent pattern now. And I think we speak in terms of decades. So to say that at the—as we do that at the present time business as currently conducted won't get us to Mars is a statement we could equally have made about the posture of NASA and our program as it stood at other points in the past. And we do believe that it will be necessary and sooner, rather than later, for the Nation, all of it, whatever Administration is in authority at the time, the Congress as it is constituted at the time, NASA, and the private space community for that matter to agree on an approach that, while it may not be everyone's favorite, everyone will agree to sustain and support over the lengthy time that will be necessary. And that we do not have today.

Chairman SMITH. Okay. Thank you, Governor.

And, Dr. Lunine, this next question is actually addressed to both you and Governor Daniels, and that is were we to say that landing astronauts onto Mars was a goal that we wanted to achieve, what are the comparative disadvantages of the Asteroid Retrieval Mission or the advantages of going back to the Moon as a stepping stone to the landing of astronauts on the Moon?

Dr. LUNINE. Mr. Chairman, we looked at what we called three example exploration pathways for getting from today to the surface of Mars.

Chairman SMITH. Yes. I think I said surface of the Moon; I meant Mars.

Dr. LUNINE. Yes, actually you said Mars in the end, yes.

Chairman SMITH. Right. Okay.

Dr. LUNINE. So these are, again, examples only, and in the end, should the Nation decide to do this, of course there may be a different set of stepping stones, a different exploration pathway. But we did look at one pathway that involved the ARM, Asteroid Redirect Mission, another that involved initially lunar sorties and then a lunar outpost before moving on to the surface of Mars, and then another pathway that we called Enhanced Exploration that involved visiting asteroids in native orbits, the lunar surface, the Martian moons, and ultimately the Martian surface.

The differences among these three pathways have to do principally with the number of steps that are available in which to develop the key technologies that will be needed to get to the surface of Mars, a whole list of technologies that I won't articulate in my answer to this question, but we can if you wish.

The ARM to Mars exploration pathway in which one goes from the Asteroid Redirect Mission to the Martian moons and then to the Martian surface has effectively the smallest number of stepping stones but the greatest technological leaps are required in going beyond ARM to get to Mars. And in particular a number of technologies that are key to landing on Mars and getting astronauts back are not developed in the context of the ARM mission. They have to be developed after that, but there are no stepping stones on which to actually test them. And some of the technologies developed for ARM are what we call dead-end technologies that are not useful as far as the committee can see in the succeeding steps to going toward Mars. So that is the essential issue with respect to that particular pathway.

Chairman SMITH. And going back to the Moon would be an advantage for the opposite reasons. Is that correct?

Dr. LUNINE. So in the pathway in which there were lunar sorties and a lunar outpost, there would be an opportunity to test technologies that would be required in partial G environments for extended stays on the Martian surface, to which astronauts would be committed.

Chairman SMITH. Okay. Thank you.

My time has expired but I want to make one more point, and that is to focus on the most recent proposed budget by this Administration for NASA and to point out that the Administration's proposed budget for NASA is \$1.8 billion less than the last budget under the Bush Administration, which seems to me that the Administration is not making space exploration a priority.

That concludes my time. And the gentlewoman from Texas, Ms. Johnson, is recognized for her questions.

Ms. JOHNSON. Thank you very much, Mr. Chairman.

It is almost comical to hear your last statement as the kind of struggle we had for reauthorization of NASA in this Committee. It had nothing to do with the Administration.

But I want to say to the witnesses, first of all, do both of you stand by the report and the contents of the report?

So you feel that it really is important for the Nation to find a way to be involved in this kind of research?

Now, Governor, I am a product of a school of Indiana, St. Mary's at the University of Notre Dame, and I know you are not a spend-thrift and—nor is Indiana as a State. And I am from Texas so you can take that for what it is worth. But if you really do think from this research that this is a goal that this Nation should achieve, do you think it is important enough to convince the people on the other side of the aisle to help us to get going because it seems to me that every day that we wait we are wasting time. We have had people in the past who had that foresight that allowed this to happen, and we are realistically in a financial bind, but we cannot shut the door to our future.

Tell me how you really feel about this.

Gov. DANIELS. First of all, thanks for mentioning your St. Mary's credential. Now I have got another reason to admire you, Congresswoman, and now I know why you turned out so well.

Ms. JOHNSON. Thank you.

Gov. DANIELS. Yes, emphatically I do agree. I want to stress, I made mention in the short opening that I do believe all of us brought to the committee an open mind. We spent a lot of time asking the fundamental question that we were assigned, should the Nation do this at all, and if so, on what basis? And that was not a reflex judgment, I don't think by anybody, let alone the whole group. And I do share it having listened to those discussions, all the witnesses, all the literature that we surveyed.

And I also would observe it is accurate to say that this is one issue, mercifully, that I don't think divides us particularly on partisan lines. I think there are people who are very enthusiastic that we heard from who may disagree strongly about other things, and people who question the value that can be found in both camps. But we hope that our report makes a strong case for proceeding and lays out, in the most candid way we could, the preconditions for succeeding, which will be much harder, I think, for folks to come to terms with than the abstract idea of whether we should go and whether we are enthusiastic about somehow finding resources.

Ms. JOHNSON. Doctor?

Dr. LUNINE. Well, I agree with Governor Daniels. I want to emphasize how broad the background of the Committee Members in fact was. This was not a committee of astronauts or aerospace engineers. We had historians, we had sociologists, we had businesspeople; there were very skeptical people I have to say right at the beginning. And I was somewhat myself skeptical that we could come to a consensus. And in the end this very diverse committee of experts came to a strong consensus on the conclusions of the report, and that to me I found quite remarkable.

Ms. JOHNSON. Thank you very much. I yield back, Mr. Chairman. Chairman SMITH. Thank you, Ms. Johnson.

And the gentleman from California, Mr. Rohrabacher, is recognized for his questions.

Mr. ROHRABACHER. Thank you very much, and I want to welcome our witnesses, especially Governor Daniels, who we have worked together in the past on many various projects that were successful and now we want to make sure that we look at America's space program and see if we can give it some direction with what we have learned.

Let me ask right off the bat, the study that we are talking about, did it come to a conclusion as to how much money it would cost for a Mars mission?

Dr. LUNINE. Congressman Rohrabacher, we did not actually try to total up and provide a final number to three digits on what the Mars mission would cost, but the technical panel in their analysis did look at the cost of various elements, developing various elements.

Mr. ROHRABACHER. Um-hum.

Dr. LUNINE. And essentially then what you would see in Chapter 4 are these sand charts that show what is required in terms of budgets relative to today in order to accomplish these goals.

Mr. ROHRABACHER. Could you give us a little hint about what they are?

Dr. LUNINE. So I will give you two numbers. One is that in order to accomplish this goal, the human space exploration program would have to rise by something on the order of two or three percent higher than inflation rate in order to meet the rising cost in the sand chart. And the total cost, as we say in our report, of a program that ends at Mars is on a scale of hundreds of billions of dollars.

Mr. ROHRABACHER. Hundreds of billions of dollars. And I would just like to say that I think that eventually humankind will get to Mars and what we really are talking about now is making sure we get to Mars earlier than what might happen 100 years from now, correct? Okay. Hundreds of billions of dollars to get to Mars a little earlier—now, maybe a little—maybe a lot earlier than what we would otherwise get there.

The—so what areas do you—as far as I can see, that means that we would have to have major international cooperation, which you mentioned with China, as well as other nations. And we would also perhaps have to make sure that the private sector got involved in space and took up some of the slack of what NASA might now be doing as part of a governmental program. Maybe SpaceX and some of these others could come in and start doing some of the more commercial type of activities.

In terms of China and space cooperation with countries like China, doesn't that sort of sit with you in a—what if somebody said in 1937 we really want to develop these rockets to go to the Moon, and you know this guy over there in Germany has really got a good rocket program; maybe we should cooperate with him. Does that—the fact that China now is the world's worst human rights abuser, isn't the fact that China now is committing acts of aggression all along the Pacific Rim with the Philippines, with Japan, and others, doesn't that sort of affect our decision as to whether we are going to cooperate with that country?

Dr. LUNINE. Well, I am going to punt part of your question over to Governor Daniels if that is okay, but I want to make one point which is that in Chapter 4 of the report, it is important to recognize that there is a very strong inflection point in terms of the budget profiles. A budget profile that only rises with inflation essentially will not get us to Mars in any foreseeable time. The program just does not close.

With respect to collaboration, one of our pathways principles is to seek continuously to engage new partners, and that can be international partners, other federal agencies, and commercial entities as well. So that is the key part of our report.

Do you want to answer the—

Gov. DANIELS. Well, the committee recognized how difficult and complex this subject is. I mean for openers—and it is important I think in every answer we give or every dimension in which we think about this subject to remember the incredible time frames

over which we are talking. Countries that are friends today might not be friends in 2040 or 2050—

Mr. ROHRABACHER. Um-hum. That is a good point.

Gov. DANIELS. —which might be as soon as we can get there under the best of circumstances and vice versa. Space has always been to some extent a place where nations that competed vigorously have found it useful or at least possible to collaborate. And Russia, not exactly the best actor on the planet right now either, but they are our intimate partner with regard to the Space Station, as the Chairman—

Mr. ROHRABACHER. Of course, we are limited—

Gov. DANIELS. —reminded us.

Mr. ROHRABACHER. —to borrowing the money from China. If we don't make them our partners, we are going to borrow it from them anyway.

Gov. DANIELS. Yes, well, this is relevant in many respects to the discussion we had.

Let me just make I think a related point and it certainly links back to the previous question, too. When we talk about the amount of money involved here, it is a lot of money, but we are talking about over decades. Now, this Committee knows, but not every citizen knows, that the NASA human spaceflight budget is a couple tenths of a percent of the federal budget, and increases in it will be rounding errors in the larger sense. We all know that the real issues with regard to making sure we can meet all our national priorities on Earth or beyond have to do with the way in which autopilot safety net programs are devouring the discretionary funds for NASA, the FBI, the Park Service, and so many other things that we value. So those two pieces I think of perspective are important when we talk about the money.

And finally, a learning point I think for me and maybe other committee members, is that a pathways approach, the committee believes, is a prerequisite to success. I will just say that there is not a lot of point in spending more money above inflation if we just spend it the way we do today.

Mr. ROHRABACHER. Um-hum.

Gov. DANIELS. So the sine qua non I think our report is pretty clear on is a new disciplined, sustained approach, the kind we try to elaborate. Given that approach, then yes, the data does say that something above flat-line spending would be required.

Similarly, with regard to partnerships, partnerships in the first instance—we look at history—turn out to be more expensive. They are not cost saving. They are the complexity, the time that is added sometimes in getting agreement can add costs, so you really will need—whether it is China or anybody else, you really will need very substantial, more than the historical levels of cost sharing first just to break even, let alone to bring down the overall burden.

Mr. ROHRABACHER. Um-hum. Thank you.

Chairman SMITH. Thank you, Mr. Rohrabacher.

The gentlewoman from Oregon, Ms. Bonamici, is recognized.

Ms. BONAMICI. Thank you very much, Mr. Chairman.

Thank you, Governor and Doctor, for being here today and thank you so much for leading the National Research Council report. We on the Committee I know really appreciate it.

You are right, Governor, that we have had a lot of discussions about spaceflight that have united this Committee and they also have the potential to unite the country. And we let our imaginations really be ignited by the incredible work done by NASA. We have had a lot of discussions in this Committee and in the Space Subcommittee about the leadership and the long-term thinking that is involved in looking at spaceflight.

We have had some interesting discussions here about the strategic direction and that is why we especially appreciate that your report—what are the benefits of going back to the Moon or do we focus on Mars, do we have the Asteroid Retrieval Mission? So we are really glad that we have your background and your expertise.

And I want to follow up on the previous conversation about international collaboration. We have talked about that a lot in this committee and I noticed that one of the things in the report that you mentioned is that it is evident that U.S. near-term goals for human exploration are not aligned with those of our traditional international partners. While most space-faring nations and agencies are looking toward the Moon, specifically the lunar surface, U.S. plans are focused on redirection of an asteroid into retrograde lunar orbit, et cetera. So can you talk a little bit about whether we should stop discussing going back to the Moon and really focus on Mars or do we need to continue to have those conversations about returning to the Moon as part of international collaboration if in fact those goals are different?

Gov. DANIELS. Well, thank you. It is an excellent question. Of course it was an observation. We had personal testimony and a chance to question leaders of every international space program and I think it is an accurate reflection of what we heard from them to say that they lack enthusiasm at least at this point for the ARM idea. They have been more interested, and told us so, in the lunar surface, and my friend Jonathan talked in answer to a previous question about the reason our committee saw some advantages to that. Going to the Martian surface, it might be extraordinarily helpful to have been on some surface first as opposed to leaping there without benefit of that direct experience.

I think that is part of the thinking of our international partners or potential partners as we heard it. But again, it wasn't in our charge and it is not part of our report to make any specific recommendation, only to say that at some stage, and we hope it is before long, the Nation needs to pick such a route and stick to it.

Ms. BONAMICI. Thank you. And I want to try to get another question in.

Dr. Lunine, you talked about the myths and it was interesting to hear you say that if we relied on public opinion polling, things might be very, very different. I have talked a lot in this Committee and we have had a lot of discussions about part of the role of NASA is to inspire students to go into science fields. I also serve on the Education Committee. We have a lot of discussions about that. Can you talk about whether NASA is doing enough to really share its successes, its potential with the public because I tell you, when we are talking with our constituents, they don't understand all the benefits of space exploration both in the short-term and the long-term and historically. So are they doing enough? Is there more that

can be done either through NASA or in other ways so that we can help to shift the public opinion and see the benefits?

Dr. LUNINE. Thank you, Congresswoman, for that question. The myth I was referring to in particular with respect to public opinion is that during the development of Apollo there was large-scale public support for that program, and in fact, what our public and stakeholders outreach panel found is that that really was not the case. But in retrospect the public supported that program looking back on it. And the same seems to be true now for the Shuttle.

With respect to your second question, we did not look in detail at NASA's Education and Public Outreach program as a committee so I can't speak to that in the context of the report. My personal experience with NASA is that it does an excellent job of providing materials through the web and other means for the public to be engaged in space exploration of all types. And I have been a part of that to some extent and I think that certainly a large part of what we do in space now is immediately accessible to the public through the web.

Ms. BONAMICI. That is right.

Gov. DANIELS. May I add just a quick word? I think because—

Ms. BONAMICI. If the Chair will allow.

Mr. PALAZZO. [Presiding] Go ahead.

Ms. BONAMICI. Thank you.

Gov. DANIELS. I do think it is a really important question and I would only add that I believe if there were secret sauce that NASA could have applied that would ignite a different level of public excitement, it would have happened a long time ago.

When we talk about a realism about public opinion, we are just trying to look in a clear-eyed fashion at the data Jonathan just talked about. And really what it says is that this will require national leadership. Many things do. Many of the great achievements of this nation and this government have not been directly responsive to a public—previous public outcry. And so what we do find in the data is that where leadership occurs and then progress occurs, the public is proud and the public then responds very strongly.

Ms. BONAMICI. Thank you very much. And my time is expired. I yield back. Thank you, Mr. Chairman.

Mr. PALAZZO. Okay. The NASA Authorization Act of 2014 was just passed the House of Representatives by a near unanimous vote. It includes the requirement that NASA develop a roadmap for the future of human exploration which defines key milestones and decision points for an expanded human presence in the solar system. Would a formal roadmap for future missions be helpful for NASA? What types of information would you expect should be included in such a roadmap? And how can NASA practically incorporate your recommendations for a sustainable program into this roadmap? That question is for both of you.

Dr. LUNINE. Congressman, the central core recommendation of our report, which is the pathways approach, essentially consists of a very specific set of steps to a horizon goal. Now, in the sense that a roadmap would embrace those specific steps, yes, that would be useful, but I think that the pathways approach goes beyond roadmaps, which often are things that have quite a bit of flexibility or

some indefinite end to them, to a process where instead there is a definite horizon goal—and this committee recommends Mars—there are intermediate stepping stones and those stepping stones have specific technological developments that are tied to them that are then needed ultimately for a landing on Mars and also the stepping stones prior to that, and then the ability if conditions do change to make reasoned and rational changes in the pathway through a set of decision rules.

So, you know, I see that as something more than a roadmap. First of all, if the Nation decides to commit to this, it is a very—how shall I say it? A very well-defined framework with pathways, with stepping stones, and with decision rules that have to be adhered to over years and decades in order to reach the final goal. It is a substantial undertaking and it is more than a roadmap.

Mr. PALAZZO. All right. Thank you.

Governor Daniels, do you want to—

Gov. DANIELS. I think that is pretty well said. I would just emphasize that it will take a level of discipline that we have not as a nation shown—so not picking on any one entity, person, branch, Administration here—the discipline to adhere to a chosen pathway, whichever it is over multiple Administrations and a lot of turnover in Congress. It is not the natural state of affairs. We all know and understand why and that is why it will be difficult to do.

The discipline to abandon dead-end technologies that will not contribute meaningfully to the technical requirements of the next step or the step beyond, the discipline to rotate resources out of infrastructure that doesn't fit the pathway as soon as it is obvious that it doesn't. So these are, as I said earlier—a lot here that people I think can agree to in the abstract will be very, very—a call on us all to approach this in a brand-new way, but that is—it is essential because the qualitative difference about this goal versus almost anything else we can think of is it takes 30 years or more to bring it off.

Mr. PALAZZO. All right. Well said.

The Administration has consistently requested less funding for the Space Launch System and the Orion Crew Capsule than is needed to keep the programs on schedule and reduce programmatic risk. The funding for Earth science at NASA has increased by 63 percent since 2007 while the overall budget has been reduced. How does your report address large priority shifts of this kind of the agency and how can Congress ensure that there is not an artificial need for an off-ramp simply because the Administration starves exploration for other priorities?

Dr. LUNINE. Well, I think the first step is that there has to be a national commitment to the ultimate horizon goal, and if there is not that strong national commitment, then it is going to be difficult to pull off human exploration missions into deep space at all. You know, we talk about Mars as the horizon goal, but all of these require very strong commitment. These off-ramps are essentially termination points for such a program, and so again it is I think a matter not so much of technical issues but political will to undertake a program like this that will cover decades.

Mr. PALAZZO. Governor Daniels?

Gov. DANIELS. I think I would just say that I don't think there is a lot of utility in talking about this Administration or any one Administration if we are going to make the national decision or sets of decisions that we think are necessary for success here. It will be something we will all have to confront in the years just ahead of us.

And so it was said earlier we are where we are and that is my view, too. It won't be just the next Administration, the next Congress, whoever makes it up, but multiple ones. We hope there will be a culture built in which there will be a presumption of discipline, a presumption of sustaining the course that is chosen over all the difficulties and all the inevitable setbacks.

Mr. PALAZZO. All right. Thank you.

And lastly, I would just like to take a moment to follow up on the questions the Chairman asked about the ARM. You know, Dr. Lunine, you stated that in the report the committee agreed that ARM would lead to dead-ends on the pathway approach. I want to emphasize that statement and reiterate my thoughts that the ARM is a costly distraction and I am hopeful that NASA will take the recommendations of this report to heart. And that is not just my personal opinion; that seems to be the majority opinion in the scientific community.

At this time I would like to recognize Ms. Wilson for five minutes.

Ms. WILSON. Thank you, Chairman Palazzo and Ranking Member Edwards. And I want to thank Governor Daniels and Dr. Lunine for being here today and for your work as Co-Chairs of the Committee on Human Spaceflight.

I agree with Governor Daniels' statement that human spaceflight should remain a major national priority and I was glad to see your committee recognize the importance of NASA and human spaceflight. In Florida, my home State, the famous Kennedy Space Center has a special connection with NASA. Many of my constituents have visited the space center and were fortunate enough to visit at least one of our Space Shuttle launches.

One of the hallmarks of this Nation is our ability to dream big and to achieve the impossible, and NASA has exemplified this spirit for more than 5 decades. As Members of Congress, we have the responsibility to keep this spirit alive. This means ensuring NASA has both the resources and guidance to continue reaching for new heights. To achieve NASA's far-reaching goals, long-term planning and sustained support are required. So I say let's keep working together in a bipartisan fashion to ensure NASA can continue its mission of discovery, technological innovation, and inspiration.

I have a couple of questions. The United States currently works with Russia, Canada, and Japan, and these are the countries that participate in the European Space Agency on an International Space Station. In your report you discussed the possibility of expanding international collaboration in spaceflight, including the potential of working with China. I recently visited China and I was concerned. What lessons are there in our current collaboration that we can apply to future collaboration to ensure intellectual property and that classified information is adequately protected?

Dr. LUNINE. Thank you, Congresswoman. We recognize that as a committee as well and we are also concerned. We also recognize that some of our traditional international partners are interested in collaborating with China as well, and whether the United States does or doesn't, we are likely to see collaboration between China and some of our traditional international partners.

Governor Daniels is prompting me to tell a story that I think is correct. I have checked it with other committee members and of course I was in high school at the time, but during the Apollo-Soyuz test project when the United States and the Soviet Union worked together to achieve the first international docking in space of two human spacecraft, the docking module which was the connector between the Apollo and the Soyuz had a Russian end and an American end and it was primarily a piece of U.S. hardware that was transported to Russia for testing and in the context of one of those transports, apparently it was found that it had been disassembled and reassembled again probably in Russian customs. So, you know, this is the sort of thing that one has to watch for.

Ultimately, if the Nation decides that China is a partner of value in this major human endeavor, the program would have to be designed to safeguard our technologies. There is no question about that.

Ms. WILSON. Okay. Thank you.

We are currently forced to rely on Russia to transport our astronauts to the International Space Station. When there is conflict between governments, how can we guarantee the concerns—the safety concerns for our astronauts? Has that been discussed or any plan in place as to what happens when there is conflict, which is something that we are fast approaching now with Russia?

Gov. DANIELS. Well, these are excellent questions and very legitimate concerns. We talked about them in the committee. I guess one can only say that we did live through periods of intense disagreement, conflict with the Soviet Union while we collaborated. We are collaborating with Russia now at a time when we have immense disagreements. These are very hard questions. And the intellectual property question of course may be even tougher.

All that can be said is as hard as those are to contemplate, as big as those risks are, the idea of somehow going to Mars alone is probably even less promising and raises even bigger questions. And so that is why our committee thinks at least we have to be open to trying to solve these problems or properly safeguard against either property theft or maybe safety challenges with regard to what is emerging as the other very vigorous, disciplined, purposeful space program on the planet.

Mr. PALAZZO. I now recognize Mr. Brooks.

Mr. BROOKS. Thank you, Mr. Chairman.

The Challenger catastrophe, as we all well know, you had one engine failure that had a catastrophic effect on all the other engines and resulted in the destruction of the Challenger Space Shuttle, including significant loss of life. Now, your report on page 4–38 claims “Falcon Heavy is designed to tolerate the loss of thrust from several engines and still complete its mission, thus enhancing mission reliability.” Given that the Falcon Heavy requires 27 Merlin 1D rocket engines to operate and given the Russian N1 moon

rocket, a system which failed 100 percent of the time, used almost the same number of engines—30—please provide the analysis to back up the claim that the number of engines improves reliability. Isn't it likely that the SLS approach of using two proven booster engines and four proven core stage engines with over 40 years of Space Shuttle flight heritage will be significantly lower risk than a mission perspective given that the risk of a catastrophic failure with six engines is less than a catastrophic failure with 27? Please comment.

Dr. LUNINE. Congressman, thank you for that question. Our technical panel evaluated a number of different technologies that would be needed for the early and late stages of a program that leads us ultimately to Mars. And as you know, the analysis was actually based on the Space Launch System, SLS, as the baseline, and in fact all of the design—so-called design reference missions of record that were used by our technical panel to put together these exploration pathways, these example pathways, they all involve the SLS as the launch vehicle.

The technical panel itself did look at other alternatives. It did include the Falcon Heavy in a brief discussion of the potential benefits and risks, but in fact none of the scenarios that are actually in the document at present utilize the Falcon Heavy as the launch vehicle.

If at some point this were to become an issue in terms of which launch vehicle to use, all of these scenarios that we have and Chapter 4 would have to be redone with Falcon Heavy in there.

But beyond that, if you want more detail on how the technical panel arrived at that particular conclusion for the Falcon Heavy, we can certainly ask our technical panel chair to provide you some written answers to how they reached that conclusion.

Mr. BROOKS. Thank you. Next question. NASA's Small Bodies Assessment Group has commented on NASA's current plan to redirect an asteroid and send astronauts to visit it. In one report the advisory group stated, "while the participants found it to be very interesting and entertaining, it was not considered to be a serious proposal because of obvious challenges, including the practical difficulty of identifying a target in an appropriate orbit with the necessary physical characteristics within the required lead time using existing or near- to long-term ground-based or space-based survey assets." Now, do you agree or disagree with that assessment and why? And if you feel that expounding is beneficial, please do so.

Dr. LUNINE. So I have actually not read that report in detail so I don't want to comment on it. And again, the task statement that we responded to in our report did not include a detailed assessment of the ARM.

All I can say again is that in the context of the example exploration pathway where we included ARM, that particular mission developed several technologies that were then not useful for subsequent stepping stones on the way to Mars, in particular the use of the solar electric propulsion, which is not sufficient to get humans to Mars, and the actual asteroid retrieval robotic vehicle. But again, this was all done in the context of that particular exploration pathway and we did not conduct a scientific or technical assessment of the ARM specifically.

Gov. DANIELS. Yes, just to emphasize that it was not in our statement of task. In fact, I think it would have been a violation of the scope of our assignment if we had opined on the merits of any specific system or proposal. The ARM we did feature in one of the three sample pathways, and I think the right way to think about those is that they are meant to illuminate tradeoffs. There are potential pluses and potential minuses to each pathway we looked at and probably any one that might be suggested in the future. And Jonathan just specified some of the downside risks of a pathway, including the ARM.

Mr. BROOKS. Thank you, Mr. Chairman.

Mr. PALAZZO. I now recognize the Ranking Member of the Space Subcommittee, Ms. Edwards.

Ms. EDWARDS. Thank you very much, Mr. Chairman, and thank you to our panelists today.

You know, as I have been listening to the discussion, one of the things that occurs to me first is that I think there is significant alignment between the House-passed authorization and the NRC's recommendations. I am a little troubled by the description of the pathway as so distinct from the roadmap because I think in this Committee, as the Chairman and I have envisioned what NASA would provide back to us, I don't see a lot of differences frankly in what you have outlined in your principles. But I view that as more semantics than anything and we could certainly be more directive to NASA in that respect in terms of what it is going to provide back to this Committee.

I am curious as to whether you think it is appropriate for the Committee to be prescriptive to NASA in terms of defining launch vehicles and specifications, interim destinations, and the like. I mean you didn't do that in your panel report of experts and so I am curious as to whether you think that is an appropriate role for the Congress.

Gov. DANIELS. Well, it can't happen without the Congress ultimately, but I think you make a very good point. This is probably not the optimal place for it to originate. What I think our committee would hope is that the Congress would unite around the very simple question, "do you want to go to Mars or don't you?" If you want to go to Mars, whether we like it or not, certain things would have to be done very, very differently and in a very unnatural act for any democratically elected government where people come and go and change would have to be sustained over this extraordinary probably uniquely long time frame that this achievement would take. And we know what we would be biting off to do that.

But I think that it would have to start with a Congress that perhaps requested, demanded a set of choices from NASA, pathway choices, embraced one hopefully on the broadest possible basis so that it might have a chance of staying power over the years, something that people could look back on and say we would be violating faith with this great adventure if we took a sudden detour, sending us off on some other direction, the way they have been sent in the past. So I see the central role in think would be Congress' but probably not the place that it originates or maybe not—

Ms. EDWARDS. So we shouldn't get into the nitty-gritty details of the technology and the science but we could leave that to the experts because I think that there has been a fair amount of unanimity on this Committee and you can see that in the authorization that passed where I think we had only two dissenting votes in the Congress that said we want—we have a big vision; we share that horizon goal of Mars and we are going to enable NASA to have the opportunity to put some teeth to those proposals.

I want to ask you about budget because, you know, if we all share that horizon goal, can you tell me just sort of ballpark if you will a budget that you think would be reflective of that goal so that we are in the 20- to 30-year range instead of the 30- to 50-year range? Because we are at roughly 4.1, \$4.3 billion now for exploration, and that doesn't include the ISS, et cetera.

Gov. DANIELS. Well, Jonathan had the first go at this so let me give it a try also. I think that quite properly the committee didn't want to go beyond expressing bands and ranges. The starting point is the ultimate budget would be driven very much by the pathway chosen. There are pathways which will be substantially more expensive, more extensive, and therefore more destinations and so forth, more expensive than others. So that is the first uncertainty. And then we just didn't want to commit the sin of false precision and start producing numbers over these long time horizons that nobody could be very confident in.

Ms. EDWARDS. So I don't think we want NASA committing to those sins either, but we do have to have a budget from the Congress—

Gov. DANIELS. Yes.

Ms. EDWARDS. —and an appropriation from the Congress that reflects the kind of big horizon goal that you have identified, isn't that right?

Gov. DANIELS. Sure. And so just to recap, the committee believes that this is a worthy endeavor, it belongs on the list of national priorities, believes that Mars is the appropriate horizon goal, but just to reiterate something said earlier, the first and prerequisite step is to—is the commitment to a pathway—maybe if roadmap means pathway, that would be great to know because that would indicate this committee was maybe prepared to take this vital first step.

With that in place, the best we were able to say was that something beyond a flat-line budget, not by a huge amount probably, but something beyond—we couldn't make the numbers work even for the least expensive pathways with constant dollars.

Ms. EDWARDS. Right. Well, thank you. I have greatly gone over my time. I will just conclude just by saying to the Chairman, and I hope that he understands this, is that if we are really to commit to this goal, if the Congress is, this is not about nickeling and diming other programmatic missions within NASA. It is really committing to it as a nation and then putting the dollars that match the goal and the opportunity.

And with that, I conclude. Thanks.

Mr. PALAZZO. I now recognize Mr. Bucshon.

Mr. BUCSHON. Thank you, Mr. Chairman. I would like to say that, you know, this is one of many hearings that we have that I attend talking about discretionary spending programs of which

NASA is one of those, and I think Governor Daniels somewhat alluded to it but I usually say this at the opening is that the federal government needs to address the entire pie of federal spending. And as we know right now, 40 percent of the budget is discretionary approximately and 60 percent is mandatory. Unless we begin to address the known drivers of our national debt, all of us are going to be continually talking about how we are going to find money to do anything, including how we are going to go to Mars.

That said, in the context of how the federal government—how NASA currently spends its dollars, when we talk about future budgets, I think—I do think it is important to talk about efficiencies and effective ways to spend that money. And it can be done at the state level. Governor Daniels has made Indiana more effective and efficient in the way we use our dollars when we know we have a fixed piece—a fixed amount of money to spend. Did the committee begin to address anything as it relates to how our current structure of the way we spend our money can be addressed in any substantial way that might not only allow us to have more money to spend than we already have but in tight budgetary times maybe use that money more effectively and efficiently?

Dr. LUNINE. Congressman Bucshon, we did talk about this of course in a general sense. We didn't talk about specific NASA facilities and so on because again we are looking at methodology rather than a specific pathway. But one of our conclusions is that if we are going to embark on a pathway that leads to Mars and do it successfully in a finite amount of time, that in addition to developing things, other things have to be ended in some way, divested in the human spaceflight program.

And so one of our pathways principles essentially says that—and I will just read it straight out; it is a decision rule—that when—“if there are human spaceflight program elements infrastructure and organizations that no longer contribute to progress along the pathway, the human spaceflight program should divest itself of them as soon as possible.” And I think this speaks to the need for the kind of discipline and focus that would be required to achieve a goal as extraordinarily difficult and expensive as ultimately a human landing on Mars.

Mr. BUCSHON. So at the end of the day, I mean obviously Congress makes those—sometimes makes those decisions. You know, I mean the A10, for example, is a recent example, you know, on the DOD side where the Congress and the federal agency may disagree on the future of certain programs. It is a very difficult process, as all of us know.

When it comes to the private sector, I am really intrigued about how we can leverage, you know, government dollars. The private sector can leverage government dollars to maybe do some things that maybe the government doesn't always do that effectively. I mean, Governor Daniels, do you have any—maybe any comments about how we might—you know, how do we leverage the private industry and what do you see as maybe their role in the future of manned spaceflight?

Gov. DANIELS. I appreciate the question because I think at least in some quarters our report has been read or misread to not emphasize sufficiently the role the private sector might play. We

didn't mean for it to be read that way that perhaps we just didn't say it loudly or plainly enough.

No, I think we heard a lot of testimony and we met with leaders of that community. There are a lot of possibilities there. And, you know, typically in this world the greatest and most sudden unexpected breakthroughs come from private enterprise and very, very likely will again and again over all the decades that we have between here and the Martian surface.

I can just testify as a fortunate person who gets to hang out with brilliant young students and graduate students studying astronautics and working in this area, they are highly motivated. And we talk about the aspirational aspects and rationales for human spaceflight and it is one of those that you can't put a number on but it doesn't mean it isn't real the way in which young people are drawn to science and drawn to technology often by this thrilling adventuresome area. I can just tell you that the activity on the private side excites our students these days probably as much as traditional NASA. And we send a lot of bright young talent to both.

Mr. BUCSHON. Thank you. I yield back, Mr. Chairman.

Mr. PALAZZO. I now recognize Mr. Posey.

Mr. POSEY. Thank you, Mr. Chairman. I want to thank both of you for your service, your service and your interest in space and your testimony here today. So many questions and so little time really to get through them.

The \$64,000 question, 64 million, billion, whatever question is how we get a consistent plan and a consistent funding level through Congress after Congress, Administration after Administration. You are familiar with the dozens of missions to nowhere and we are afraid that we will see more and more of these. You know, you remember the ISS survived just by one vote, funding for the ISS at one time.

And another approach that bears a lot of sense is the XPRIZE approach. And since there is really no good business model for exploring space, the XPRIZE process gives a lot of encouragement to that obviously, a lot of encouragement to private investment, technology development, risk. And I wonder if you have considered that process as well and what you might think the dollar amounts might be or the milestones might be.

I mean we can have NASA maybe design a car to make three laps around the horseshoe in front of this building, and by the time they are finished it could be a \$5 million car. We can say the first person that can design a car to make five laps around the building gets \$1 million and, you know, it would be done in five minutes by private industry and we would save a lot of money and have always wanted develop for us already. It has been said by experts, you know, the Wright brothers would have never flown if they would have had to put up with FAA, and I am afraid that goes for a lot of space entrepreneurs.

You know, this is a very difficult country to do business in and you have to take your hat off and respect any of them that choose to do business here with the overregulation and the red tape that we foist upon our space industry. While other governments subsidize theirs, we hassle ours. So your thoughts on that?

Dr. LUNINE. Thank you, Congressman.

We didn't talk about the XPRIZE or again we didn't talk about specific commercial approaches because it wasn't part of our task statement or charge. But I do want to point out that we, in the approach that we developed, the pathways approach, leave the door wide open for commercial innovation in the stepping stones that would lead us ultimately to Mars. And again, I will quote from the pathways principles that we developed in our report, and number four is to "seek continuously to engage new partners that can solve technical and/or programmatic impediments to pathway progress." And those partners can be governmental, they can be international, and they could be commercial as well. And without that flexibility, certainly any pathway approach is not going to be optimal. We have to be able to involve whatever new ideas and creative approaches that can be brought to bear on such a difficult problem as landing on Mars.

Now, the question of, you know, how to encourage commercial endeavors, again, it is beyond the committee and I don't feel particularly qualified to say anything about that. I will say, though, that the overall problem of sending humans to Mars and landing them on Mars, even through this stepping stone approach, where you do this in progressive steps that are manageable enough that there is a reasonable chance of success for each one, is such a huge endeavor that it must involve the U.S. Government as the primary mover of this whole endeavor just because of the size and scope. And within the context of that, this committee believes there is ample room for commercial and international involvement, even it is essential for that involvement.

Mr. POSEY. Thank you. Governor?

Gov. DANIELS. Nothing to add. I think that is—

Mr. POSEY. Well, Governor, you have dealt—you have seen one Administration after another, dealing with one House and one Senate after another.

Gov. DANIELS. Right.

Mr. POSEY. You know, what do you think the common denominator might be to tie this together? You know, we are all searching for that continuity, everybody, no matter what direction they are coming from in space. You need to have a plan, you all need to stick to a plan, and it needs to be a long-range plan, not plan du jour, you know. It needs to be a long-range plan and we just can't find that glue that will tie that together.

Gov. DANIELS. You put your finger of course on the central dilemma. I said in the opening our report says in almost the same words that we recognize that calling for an approach like this flies in the face of everything back to the '70s I suppose, but we also say that if it seems unrealistic to believe that that sort of unity and that sort of continuity could be brought off in our system, then you might as well face up that Mars itself is unrealistic.

Now, I am going to engage in some wild wishful thinking here, but I do think—and it was reflected in comments that the Ranking Member made earlier and others did—at least in theory this could be one of those subjects that we certainly need more of in this country in which people who disagree strongly and sincerely about other things could agree, particularly if folks accept the reality that if we are going there at all, it is going to have to be on this basis.

We are going to have to hold hands not just in the first Congress that agrees to it but that has got to be transmitted somehow to those who follow.

And, yes, that is not the natural state of affairs but this is not like any other endeavor that I can think of that government or the private sector for that matter attempts to bring off. And I appreciate your question and I think it is in some respects the ultimate question here, and forgive me for indulging in the thought that maybe it could all start right here.

Mr. POSEY. Well, you know, we would like to see that. It just seems like anything short of getting America out of the mall for 15 minutes and away from Dancing with the Stars for 15 minutes and letting Neil deGrasse Tyson talk to each one of them for 15 minutes, you know, we could probably pass a constitutional amendment to fund that. But, you know—I see my time is expired. Thank you, Mr. Chairman. I yield back.

Mr. PALAZZO. I now recognize Mr. Hultgren.

Mr. HULTGREN. Thank you, Chairman. Thank you both so much for being here. I really appreciate your work on this. This is a very important subject.

On a personal note, Governor Daniels, just want to say thank you for your work. I am a big fan of yours. I am from Illinois, enough said.

I do want to thank you. I believe this is so important. As we continue to assess a future of human spaceflight in the United States, we need to have this discussion. It is certainly something I want to see America leading in and it is crucial that we get both public and international support to see this happen.

I wonder—and I address to both of you on this—there is an important connection between motivating students to pursue STEM careers and having a visible active human spaceflight program. Motivating students to pursue these fields is an important factor in the success of certainly future space endeavors. How did the panel factor in this need into its recommendations?

Gov. DANIELS. Let me start because I think it surfaces a really important point that hasn't come up, up to this point. So, first of all, we talk about it at great length, agree that like two or three other rationales for human spaceflight, it can't be quantified—that doesn't make it any less real or important—and came to the conclusion that when you roll together those practical or pragmatic reasons with those aspirational, as we called them, reasons, the totality did justify treating this as a priority.

The point I would like to make on this count is that over and over the idea of mission frequency, sometimes called cadence, that is to say, what came up for at least two reasons; one, to maintain the technical proficiency necessary for an endeavor like this. If you are only flying every three or four years, you are losing people, you are losing skills, you are not developing, you are not making enough mistakes probably to learn from, all those things. And you are probably not sustaining public interest among either young people or their elders. And so if you do spend some time in the report, you will see frequent references to this matter of mission cadence and I just wanted to use your question as an opportunity to raise it here.

Mr. HULTGREN. Thanks.

Dr. LUNINE. Yes. And if I could just add briefly, Congressman, your point is very important. This is one of the pragmatic rationales that we talk about in the report as stimulating and inspiring students as well as citizens in general. And, you know, the counterfactual of what would happen if there were no human spaceflight program in terms of what the next generation of aerospace expertise would look like in this country, obviously that would not be a positive change.

Mr. HULTGREN. Yes. And I agree so much with you and I have to remember back to the '60s of, you know, the inspiration that was there but also the benefits—multiple benefits, years and years, decades of advancement in that single decade in medicine and other areas because of the inspiration that was there.

Governor, I agree with you as well that we need to find some things that bring us together. This is one of those things that can bring us together. We all agree that we want to encourage our best and brightest to go into STEM education and STEM fields, and this is one of the ways that we can do it at an early age, capture their attention. I wonder if both of you, can NASA accomplish a mission to Mars without the international community or is that a prerequisite according to your research and report?

Dr. LUNINE. From the point of view of the committee's deliberations, in principle the United States could do it, but it would be extremely costly, and for a number of different reasons. Having significant international collaboration—and here we are talking about international collaboration on a scale in terms of percentage contributions that we have not even seen with the ISS, from a numbers standpoint, international collaboration is extremely valuable, both from the point of view of bringing new technical expertise support on an international basis for these types of activities and the symbolism of going forward with international partners to a new goal. All of these things make international collaboration highly desirable in this endeavor.

Mr. HULTGREN. Let me end with this and again offer this out to both of you. I wonder how emphasis on unfocused space technology development in this Administration hampered NASA's ability to focus on long-term goals of human exploration. In particular, I am interested in J-2X and how that impacted exploration missions in other areas, specifically kind of this unfocused space technology development? Any thoughts on that?

Gov. DANIELS. Well, no specific comment on that or any other one technology except to say that the committee strongly feels that an emphasis on capabilities has often led to dead-ends or unproductive investments and that we really need to ask the question from the other end. Where are we going? What are the steps on the way to get there? And let that drive the technical and engineering requirements, and therefore the capabilities one develops.

Dr. LUNINE. Well, I would only add that your question cuts right to the heart of our report, which is a capabilities-based approach in our view is not going to get this nation or anyone to Mars, that we needed to have a pathways approach where technologies are developed in the service of the ultimate goal and the stepping stone intermediate goals to that end.

Mr. HULTGREN. My time is expired. Thanks, Chairman. Thank you again both. I really appreciate your work and look forward to an ongoing effort here together, hopefully move this forward.

I yield back.

Mr. PALAZZO. I now recognize Mr. Veasey.

Mr. VEASEY. Thank you, Mr. Chairman.

Governor Daniels, Dr. Lunine—and I apologize; I just got here, and if this question has already been asked—but I wanted to ask you specifically in what sequence does NASA need to implement your recommendations in this committee's report for everything to take place smoothly?

Gov. DANIELS. Well, the sequence I think that matters most, Congressman, is the commitment to a pathways approach and the selection of a pathway, followed by the commitment to sustain funding for that pathway. I would put them in that order very purposefully because we did talk a little earlier, more money spent in the way we have been doing for the last several Administrations probably doesn't advance things very far.

Mr. VEASEY. And also, the report recommends a pathways approach over both a capabilities approach and the flexible path approach, but we don't need a flexible path approach to mission planning in order to deal with these unexpected changes in the budget and to take advantage of technology breakthroughs. Is that your opinion or you think that we—or it is the opposite of that?

Dr. LUNINE. Well, what the committee finds attractive about the pathways approach is that it streamlines the development of technologies in the sense that, again, to get to Mars as the ultimate horizon goal is going to be extraordinarily difficult, and so the technologies that will need to be developed are expensive and they are difficult.

And so one wants—if one is committing as a nation to going to Mars—to adopt an approach that minimizes the number of additional technologies that have to be developed on the way to Mars because they are all expensive and they all of course take time, and that plays into the ultimate timeline of any program that leads to Mars. So the pathways approach is the way to minimize the total number of technologies that have to be developed in order to achieve the ultimate horizon goal, in this case, Mars.

Flexible path approach, you may end up developing technologies that in the end are not useful and are not therefore, you know, ultimately contributing to the final goal that you want to get to.

Mr. VEASEY. Thank you. Thank you, Mr. Chairman.

Mr. PALAZZO. I thank the witnesses for their valuable testimony and the Members for their questions. The Members of the Committee may have additional questions for you and we will ask you to respond to those in writing. The record will remain open for two weeks for additional comments and written questions from Members.

The witnesses are excused and this hearing is adjourned.

[Whereupon, at 11:36 a.m., the Committee was adjourned.]

Appendix I

ANSWERS TO POST-HEARING QUESTIONS

ANSWERS TO POST-HEARING QUESTIONS

*Responses by Governor Mitch Daniels*Responses to Questions for the record for Gov. Mitch Daniels from Representative Lamar Smith:

1. One of the “decision rules” given in the report is that if the appropriated funding level and five-year budget projections do not permit execution of a pathway, then the Nation should not go down that particular pathway. In recent years the Administration has consistently requested less money than is needed for the exploration development programs. How can Congress reconcile a situation like this with your recommended decision rule?

It would best to follow the pathway principles as laid out in the report and utilize the decision rules properly. While a proper budget is important, the decision rules and pathway principles give guidance for what to do in times of uncertain budgets.

2. NASA officials assert that the asteroid retrieval mission is the only stepping stone to Mars which the country can afford right now. How could NASA reprioritize its budget to use both schedule flexibility and rolling development projects to meet milestones to Mars?

The committee was not charged to give specific budget guidance to existing programs. The question of which pathway is chosen and budget approved should be informed by discussions between Congress, the Administration, and NASA, of the nation’s priorities. Once a pathway is chosen, it will be important for the nation to commit to a sustained and disciplined investment for that pathway. However, the committee’s assessment determined that it is impossible for a U.S. Mars program to be executed without an increase in NASA’s budget.

3. The Government Accountability Office routinely lists NASA acquisition management in its biennial high risk series. The NASA Authorization Act of 2014 includes direction to NASA for using better cost-control methods in program management and planning. One of the recommendations for a sustainable program was “redirecting human spaceflight resources as needed to include improving program management efficiency.” What specifically do you recommend?

The committee was not charged to address the specifics of internal NASA resource allocation and therefore the committee did not conduct the kind of review of resources that would have allowed it make recommendations in this area. However, many of these issues are well known and have been discussed by government administrators and policy makers many times over the years. In the context of a pathways approach, divesting obsolete or dead-end technologies after each step will be necessary to improve efficiency and reach the horizon goal.

4. One challenge facing NASA and most agencies in the federal government is long-term budget uncertainty. This is especially difficult for an agency that handles long-term high tech development programs. What recommendations did the panel make that could assist NASA in coping with this type of uncertainty?

In the report are provided what we call the “Pathway Principles” that will help in the choice of a consensus pathway to the horizon goal and “decision rules” that will serve as guidelines on how to

manage the pursuit of the chosen pathway when stressors, such as diminished budgets arise. In order to cope with budgetary and technical uncertainty, NASA will need to follow the pathway principles and decision rules as laid out by our report in section 1.6.3. Budget stability is also closely linked to programmatic stability, and the report points out that exploration as part of a partnership has the potential to enhance the stability of an ongoing program.

5. Your report is the latest in a long line of reports on human spaceflight since 1986 addressing similar concerns. How does your report differ from those and what can Congress do to ensure NASA incorporates your recommendations?

As described in detail of the Preface of the report, the scope of this study was broader than previous studies and considered questions in a range of disciplines. This report also reconsidered all current and historical rationales for the human spaceflight program to determine whether the activity should remain a national priority. In addition, the committee was designed to be remarkably diverse; it featured human spaceflight experts, scientists, public opinion polling experts, historians, individuals with flight experience, and more. In order for Congress to ensure NASA incorporates the report's recommendations, once a pathway is chosen by the nation, Congress should support this pathway and commit to it through multiple decades.

6. The National Science Foundation released a poll this year which showed that Americans are interested in "new scientific discoveries."
 - a. What role does public support play in ensuring the stability of the human exploration program? How do we garner more public support?

It is unlikely that the pursuit of human spaceflight could be justified solely on prior public support or pragmatic rationales alone. However, when a human spaceflight program is successful, such as the Apollo Program or the Shuttle, the public views the expenditure retrospectively with great pride as a matter of national importance. The report does not make recommendations on how to increase public engagement with human spaceflight activities, however I personally believe that a program that regularly and successfully accomplishes exciting and challenging goals will be embraced by the public.

7. Last year, the Space Subcommittee held a hearing with representatives of private industry to discuss partnerships between the government and commercial space companies. One of the witnesses, Dennis Tito, Chairman of Inspiration Mars Foundation, spoke about his idea for a public-private partnership on deep space exploration.
 - a. What role do you see for private industry in the future of human space exploration?

As per pathway principle IV, new partners should be continuously sought out that have the ability to assist in solving technical or programmatic blocks along any chosen pathway.

- b. Should the inclusion of private partnerships play a central role in the development of future human space flight plans?

The committee did not make a judgment about what role private partnerships should play in the pathway but encourages NASA to seek out partners who can solve technical or programmatic challenges on a pathway. These would of course include commercial partnerships. However, at the present time, the U.S. government is the only actor large enough to realistically be the primary driver behind a Mars expedition.

- c. How would you structure these types of partnerships?
- d. What risks are associated with reliance on private partners?

The committee did not address questions C and D specifically, however the report describes at length how challenging it will be to go to Mars and so these would certainly be risks to consider in structuring partnerships.

- 8. The NASA Authorization Act of 2010 was signed by the President in October of 2010. This legislation directed the Administration to contract with the National Academies for this study. According to your report, the study did not begin until the first half 2012. Why did it take two years for work to begin on the report?

Congressionally mandated studies, like this one, involve not only negotiations with NASA officials but also discussions with congressional staff to make sure the negotiated contract terms and conditions are consistent with congressional expectations. Many factors, such as the complexity of the statement of task, coordination with interested government agencies, and securing the necessary funds to start the project, can add time. In this case, there was an extended period of discussion with NASA and other government agencies such as the OMB, leading up to the finalization of the Statement of Task for this study. Congressional staff was kept informed by the NRC throughout the discussions. This period of activity is described in more detail in the Preface of the report. While two years is a long time for a study to get started it certainly is not without precedent.

- a. What NASA officials were involved in formulating the 'Statement of Task?'

During the task negotiations, there were several departures of the involved NASA staff. Thus, the NRC staff worked with three successive points of contact at NASA and these were Laurie Leshin (then Deputy Associate Administrator, Exploration Systems Mission Directorate), Lynne Cline (then Deputy Associate Administrator for Human Exploration and Operations), and John Olson (then Director, Strategic Analysis and Integration Division). The departure of each point of contact naturally led to some additional delays. In addition to these main points of contact, NRC staff also met with both NASA Administrator Bolden and Deputy Administrator Garver during the negotiations.

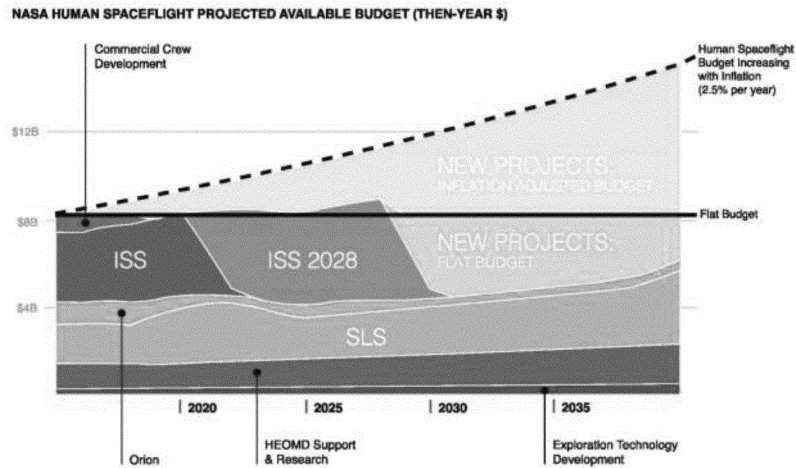
- b. What is the average time it takes for the Academies and NASA to agree to a 'Statement of Task?'
- c. Have the Academies ever taken this long to get a study started?

Across the Academies, studies can take anywhere from a few weeks to a few years for a statement of task to be agreed on and the funding to be provided. Given the amount of variation with studies

themselves and between boards, there is not a useful average representative time of the time it takes to start a study.

9. The Constellation was a “system of systems” approach that included a lunar lander. NASA contends that a lunar lander would be very expensive and we simply do not have the money for such an endeavor at this point.
 - a. Does NASA need to develop a lander in parallel with the development of SLS and Orion, or can NASA develop a lander later?
 - b. Could NASA develop a lunar lander within the current budget profile by using time-phased development and schedule flexibility?

Whether or not a lunar lander is developed would depend on the pathway selected. At the present time, agreement to take a pathways approach, selection of the pathway, and then providing the budget necessary to actually implement that pathway is necessary first. With NASA’s current budget, essentially no money is available for new projects until after the decommissioning of the ISS.



Responses to Questions for the record for Gov. Mitch Daniels from Ranking Member Johnson:

1. Your report recognizes that a number of previous blue ribbon and advisory panels have provided guidance and recommendations on the nation’s human spaceflight program and have recommended Mars as the ultimate goal. In your view, why have those previous efforts not led to achievement of the goal?

The report recognizes the need to commit to and sustain a long-term plan to reach the horizon goal of Mars. It is likely that there are various reasons that policymakers have chosen not to act on previous reports at those particular times. However in order to reach Mars, a pathway must be committed to and sustained across multiple Congresses and Administrations and we all recognize that this is an extremely difficult challenge.

2. You mention “practical” and “aspirational” rationales for human space exploration. What are some the practical rationales to which you refer?

The practical rationales include: economic benefits, national security, national stature and international relations, inspiration of students and citizens, and scientific discovery. More details about these can be found in section 1.4.2. of the report.

3. Does a selected pathway have the flexibility to allow future Administrations and Congresses to make an imprint on the future of human space exploration while meeting the need, as stated by the NRC, to sustain the stability of the pathway?

Major changes to a pathway by future congresses and administrations would undercut the human spaceflight program and make it no more effective at achieving deep space goals than it is currently. The most valuable impacts that future congresses and administrations could have would be those that require and enable NASA to follow the pathway principles and decision rules as laid out in this report.

4. How can Congress ensure that an interim step or milestone does not detract from making continued progress on the long-term goal of sending humans to Mars, even when the activities and potential discoveries related to an interim step are compelling, inspirational, and significantly productive for other reasons?

When an interim step is no longer producing compelling inspirational or scientific results, the step and associated technologies would be divested in pursuit of the Mars surface goal. The pathway approach has the flexibility to accommodate continued exploration of interim destinations along the way if the nation finds them to be compelling in their own right, while still maintaining a long-term focus on the horizon destination of Mars.

5. If we continue to pursue the current NASA plan, including spending \$6.5B per year on human spaceflight for the next two decades (total of \$130B) when will we be able to land humans on the surface of Mars? What will be needed to achieve a human landing on Mars within a reasonable timeframe?

Current funding levels do not bring humans to Mars in any realistic timeframe. The project lifecycle cost for human exploration beyond low earth orbit will be on the order of hundreds of billions of dollars. For increased funding to be effective in reaching Mars, the nation must commit to itself to a pathways approach first. Then, NASA’s human spaceflight budget would need to increase modestly faster than the rate of inflation annually for an extended period of time. Even then the first mission to the Mars surface would not take place until the late 2030’s or 2040’s.

6. The NRC report recommends that “if the appropriated funding level and projected 5-year budgets projection do not permit execution of a pathway within the established schedule, then do not start down the pathway.” As you well know, outyear budget profiles are notional and often do not reflect what is appropriated in those future years. Is it realistic to make decisions not to pursue a pathway under such criteria?

The committee recognizes that budget projections are unreliable, but they are also indispensable. One way to make the use of such projections more robust would be for NASA to conduct sensitivity analysis and evaluate plans against a range of possible 5-year budget projections that may vary by 10 percent or more. This might be done as part of the risk mitigation plan.

Responses to Questions for the Record from Representative Joseph P. Kennedy III

1. In addition to an adequate budget, what if any legislation from Congress is required to implement the recommendations set forth in your report?

It is difficult for the committee to recommend specific legislation, however, the cost and lengthy duration of human space exploration program whose goal is Mars will require significant and sustained leadership by the Federal government.

2. What is the biggest challenge facing NASA human space exploration to make it sustainable in the long-term, and what are specific actions that can be undertaken to mitigate it?

NASA lacks a long-term, detailed plan for human spaceflight, in part because the nation as a whole has not committed to such a program. In order to combat this, a culture needs to be built around sustaining the pathway through multiple Congresses and administrations. This is discussed more specifically in section 1.2, which gives an overview of U.S. space policy and in section 4.4, the Key Results from the technical panel.

3. What are your thoughts on the sources of sustainability necessary to not only getting to Mars, but also to keep us returning? The Apollo missions were focused on a goal of getting us to the moon, but once we got there that was it. We keep saying “we have to get to Mars,” but in your opinion, how do we make sure that we keep returning?

The committee does not recommend an Apollo type effort for human exploration, because the latter was not sustainable. The recommendations in the report are geared toward a program that achieves meaningful milestones in human space exploration over many decades on the way to and at Mars. Taking a pathways approach would mean that the U.S. human spaceflight capabilities would be developed in an orderly fashion, with regular milestone accomplishments, and whose success of necessity would involve an entire generation of Americans from childhood to adulthood in the saga of exploration beyond low earth orbit.

4. In the Pathway Principles, the first exploration pathway characteristic is that “The horizon and intermediate destinations have profound scientific, cultural, economic, inspirational, or geopolitical benefits that justify public investment.” NASA is primarily an organization of, and managed by, engineers and scientists. How would you suggest that NASA shape a pathway to have profound cultural, economic or inspirational benefits?

Despite being composed principally of scientists and engineers, NASA does have an understanding of which destinations produce important cultural, economic and other benefits. However, it is not up to NASA alone, or even primarily, to choose a pathway; rather, it will be up to the nation through Congress and the administration—with the guidance of NASA expertise—to select and pursue a meaningful target.

*Responses by Dr. Jonathan Lunine*Answers to Questions from Chairman Lamar Smith for the record addressed to Dr. Johnathan Lunine:

1. As we seek to push the boundaries of human reach into the solar system, we will need focused efforts to develop game-changing technologies. In the course of developing the architectures associated with deep-space exploration, what new technologies would you expect will be needed?
 - a. Can a deep space exploration architecture be accomplished with steadily evolving technology development, or will it require revolutionary, "game changing", breakthroughs?

The feasibility of all proposed concepts for Mars entry, descent and landing for human missions remains to be demonstrated, and adequate technical, biological, and/or pharmacological solutions for radiation hazards have yet to be identified, so substantial technical or even conceptual breakthroughs may be needed. Many of the other technologies in the report are incremental and, while requiring investment, do not require conceptual breakthroughs.

2. Some experts before our Committee have endorsed the "so-called" flexible path which is a focus on technology development rather than a destination. Your report clearly endorses a different way of thinking about getting humans to Mars by "developing a program through the rigorous application of a set of pathway principles".
 - a. How has the emphasis on unfocused space technology development by this administration hampered NASA's ability to focus on the long-term goals of human exploration?

There is a lack of a clear consensus by the Administration and Congress as to the goal of human space exploration and the intermediate steps toward that goal. Absent these two critical elements for a long-term human spaceflight program, any technology development at this juncture is by definition unfocused.

- b. How can NASA reconcile technology development priorities with exploration priorities?

After a pathway is selected and funded, the human spaceflight technology priorities will need to flow from the exploration priorities. In order to reconcile technology development priorities with exploration priorities, a pathway must be committed to and sustained by NASA, Congress, and Administrations for the long term.

3. The report mentions that the panel reviewed several possible pathways. Can you give the Committee a sense of those pathways that you reviewed but rejected as possibilities and why?

The three pathways detailed in the report are examples that illustrate the various tradeoffs among key factors such as schedule, development risk, affordability, and technology feed forward. Altogether, the three pathways include a total of five intermediate destinations, in addition to the horizon destination of the Mars surface, and seven design reference missions. (There are two design reference missions to the moon, a lunar sortie, and a lunar outpost.) These were chosen for exposition

because they span the likely programmatic space and thereby provide good insight into the range of affordability and technical difficulty. In developing the set of three pathways that appear in the report, the Technical Panel considered alternate pathways with different combinations of the seven design reference missions. The Technical Panel did not review these alternates; it only assessed the three identified in the report.

4. Experts have testified before this Committee that NASA should concentrate on developing the most important enabling technologies for a Mars mission. One of your recommendations for a sustainable program is a concentration on entry, descent, and landing for Mars, advanced in-space power and propulsion, and radiation safety.
 - a. What criteria should be used to determine which technologies will be the most useful to a Mars mission and what did the panel us to identify these technologies?

A manifold set of technologies and capabilities is essential to the success of a human mission to the Mars surface, so utility in and of itself is not a good parameter for determining where to invest scarce R&D resources. The committee concluded that there are 10 high priority capabilities for which R&D resources should be made available as described in the report. These high priority capabilities were identified by assessing candidate capabilities using four criteria:

- Technical challenges
- Capability gap
- Regulatory challenges
- Cost and schedule challenges

	HIGH	MEDIUM	LOW
TECHNICAL CHALLENGES	Technical solution currently unknown or unattainable with current technology	Solution is known but not well understood	Solution is well understood with current or previous relevant research
CAPABILITY GAP	No relevant systems exist or have existed at the appropriate scale	Systems exist or have existed that are scalable to mission needs	Systems exist that are translatable or are easily scalable to mission needs
REGULATORY CHALLENGES	Current regulations impose significant restrictions and will be difficult to change	Current regulations impose a challenge	No regulatory issues
COST & SCHEDULE CHALLENGES	Development to operational capability is on the order of previous large, national programs (Shuttle Orbiter)	On the order of Apollo Heat Shield or Orion ECLSS	< 5 years development with < 50 person team

FIGURE 4.8: Capability assessment criteria.

- b. Are there any specific technologies currently being developed that you think should be put aside or delayed?

The committee was not asked to look at specific technologies to set aside or delay. However, the high priority and challenging technologies for Mars missions are discussed in Chapter 4. The committee

notes that if the U.S. is serious about Mars exploration, work should begin immediately on the most difficult technologies, specifically Mars entry, descent, and landing (EDL), in-space propulsion and power, and radiation protection.

5. In its development of the recommendation to work more with China, did the committee examine NASA's current practices for protecting sensitive information and how those practices could be modified to ensure partnerships with China would not compromise that information?

The committee did not make a recommendation to work with China but did conclude that it is in the best interests of the United States to be open to partnering with China. The committee was well aware of the various sensitivities associated with working with China and recognizes that appropriate and effective safeguards will likely have to be put in place. There is a historic parallel in that the U.S. has found it productive to cooperate with potentially adversarial nations in the past as exemplified by the Apollo-Soyuz mission, joint with the Soviet Union during the cold war.

6. The panel recommended greater cooperation with China. What areas are appropriate for cooperation given China's secretive programs? For example, could the U.S. and China cooperate on common docking standards and orbital debris mitigation and tracking?

While common docking standards or orbital debris mitigation may well be important for future joint operations in low Earth orbit, the intent of the committee's conclusion on remaining open to working with China was broader: if international cooperation is to defray significantly the cost of a U.S.-led human mission to Mars, international cooperation will need to be on a scale much greater than in the past. Given the limited number of potential partners who could significantly contribute, the U.S. should be open to fully engaging China as a partner in human exploration beyond low earth orbit. This would entail shared decision-making processes and international contribution corresponding to a major fraction of the mission costs.

7. When making the recommendation for further cooperation with China, what type of analysis did the committee do to weigh the risk of economic and scientific losses against the envisioned gains?
 - a. Did the committee interview cybersecurity and corporate espionage experts in developing this recommendation?

The committee was sensitive to these issues in its discussions, but such an analysis was not part of the committee's charge.

8. Your report is the latest in a long line of reports on human spaceflight since 1986 addressing many of the same concerns. How does your report differ from those and what can Congress do to ensure NASA incorporates your recommendations?

As described in detail in the Preface of the report, the scope of this study was broader than previous studies and considered questions over a wide range of disciplines. As a consequence, the committee and its panels were composed of a remarkably diverse group of experts: astronauts, engineers,

technologists, scientists, public opinion polling experts, historians, sociologists, and more. A key difference with respect to the conclusions of this report is the recommendation of adopting a pathways approach for future human spaceflight programs, in contrast to the more flexible approaches of prior reports.

Answers to Questions from Ranking Member Johnson for the record addressed to Dr. Johnathan Lunine:

1. Your report's pathway principles explicitly mention budgets and suggest that if the available budget were insufficient to complete a pathway, NASA should take an "off ramp", switch to a different pathway or stand down.
 - a. How would you define an exploration program "off ramp"?
 - b. What was your intention with this principle?
 - c. As a practical matter, how can NASA actually make that decision, given that budgets are appropriated yearly and it never knows from one year to the next exactly what its budget will be?
 - d. How realistic is the use of potential "off-ramps" for a long-term human exploration program once it is underway? Are there any past examples where using "off-ramps" have been particularly successful?

An off-ramp is a move to a different, usually less ambitious, pathway. The intention is that the program should be sustainable in face of a reduced budget or uncertain budgets. It is up to Congress how they would like to address appropriations issues. If desired, multi-year appropriations processes could be used. However, the committee recognized the unprecedented duration of commitment that a human exploration program with Mars as its goal entails.

2. The report recommends a pathways approach over both the capabilities approach and the flexible path approach, but don't we need a flexible approach to mission planning in order to deal with unexpected changes in budget and to take advantage of technology breakthroughs? If not, why not?

The flexible path approach mentioned in the report describes a program that develops technologies without a horizon goal in mind. In the committee's approach, unexpected changes in funding or technological opportunities are handled through the decision rules that we detail as part of our recommendations.

3. Not surprisingly, your panel recommends that NASA divest itself from infrastructure that is no longer contributing to progress along the chosen pathway. Yet, as you know, NASA has struggled with modernizing its facilities and maintaining those it must keep, and there can be Congressional pressure to preserve infrastructure. Do you have any recommendations on how to break the infrastructure logjam?

The scope of this study did not include NASA's present infrastructure issues, and as such there are no specific recommendations from the report. However, dealing with NASA's infrastructure issues will require a great deal of policy leadership and collaboration between NASA, Congress, and the Administration.

4. The report seems to suggest that the cost of continuing to operate the ISS could be a major barrier to developing the systems we will need to go to Mars. Is the committee suggesting that the lifetime of the ISS should not be extended?
 - a. How important is the ISS to making progress on a pathway and on the key technologies and capabilities identified in the report?
 - b. What was the view of the committee in terms of how a decision on the duration of ISS operations should be made?

The ISS serves as an important microgravity laboratory, however it also uses a significant fraction of the limited human space exploration funds. The committee recognizes that this presents a dichotomy. The ISS represents a uniquely effective platform for the study of long-term physiological effects of microgravity. However, unless significant additional resources are identified, continued operation of the ISS will delay the start of a serious human exploration program aimed at Mars. The committee recognizes that both the benefits and drawbacks of an ISS extension for human spaceflight plans will have to be carefully weighed, along with the benefits of ISS continuation that are unrelated to human spaceflight.

5. The panel stated that the lower the operational tempo, the more difficult it is to retain critical technical capabilities and operator proficiency, and to effectively utilize personnel and infrastructure. How serious of issue is the launch tempo to ensuring safety of human spaceflight operations?
 - a. Is this issue specific to SLS or was the committee referring more broadly to government and potential commercial crew missions overall?
 - b. Are we already at risk of losing our edge as a result of no longer having scheduled Shuttle missions?
 - c. Since we still continue to launch unmanned space sciences missions, what are the skill, operator proficiency, and safety aspects unique to human spaceflight that we are at risk of losing?

Under the most likely budget scenarios, the low flight rate of the SLS would be without precedent for the human spaceflight program. The lower the operational tempo, the more difficult it is to retain critical technical capabilities, to retain operator proficiency, and to effectively utilize personnel and infrastructure. This issue may be relevant to any launch system, commercial or government, with a capacity comparable or close to the SLS. With regard to crewed launches, neither NASA nor any other entity in the United States has launched one since the last shuttle. Industry has continued to launch

uncrewed cargo missions, but NASA has not launched any missions of its own since the retirement of shuttle. The deleterious effects of a low flight rate are detailed in chapter 4 of our report.

6. Your report talks about the fact that the international partners want to go back to the Moon.
 - a. In your panel's view, is this a sufficiently compelling reason for the U.S. to consider doing so as a pathway?

It is one important reason to consider that pathway, but it is not the only reason for the U.S. to consider a pathway including lunar return. While the committee endorses no particular pathway, any pathway involving extended stays on the lunar surface has several advantages, including for example, providing technical and operational experience in a partial-gravity and dusty environment.

- b. How realistic is it to assume that there would be a significantly increased level of resources provided by international partners to the goal of sending humans to Mars if their focus is the moon?

Exploration of the moon is a near-term goal of many partners. Given the interest of potential international partners in a return to the moon as an intermediate step, it makes sense to expect increased investment from them along this pathway. However, all long-term space programs by all potential international partners converge upon Mars as the horizon goal.

Answers to Questions for the Record from Representative Joseph P. Kennedy III

1. In addition to an adequate budget, what if any legislation from Congress is required to implement the recommendations set forth in your report?

It is difficult for the committee to recommend specific legislation, however, the cost and lengthy duration of a human space exploration program whose goal is Mars will require significant and sustained leadership by the Federal government.

2. What is the biggest challenge facing NASA human space exploration to make it sustainable in the long-term, and what are specific actions that can be undertaken to mitigate it?

NASA lacks a long-term, detailed plan for human spaceflight, in part because the nation as a whole has not committed to such a program. In order to combat this, a culture needs to be built around sustaining the pathway through multiple Congresses and administrations. This is discussed more specifically in section 1.2, which gives an overview of U.S. space policy and in section 4.4, the Key Results from the technical panel.

3. What are your thoughts on the sources of sustainability necessary to not only getting to Mars, but also to keep us returning? The Apollo missions were focused on a goal of getting us to the moon, but once we got there that was it. We keep saying "we have to get to Mars," but in your opinion, how do we make sure that we keep returning?

The committee does not recommend an Apollo type effort for human exploration, because that was not sustainable. The recommendations in the report are geared toward a program that achieves meaningful milestones in human space exploration over many decades on the way to and at Mars. Taking a pathways approach would mean that the U.S. human spaceflight capabilities would be developed in an orderly fashion, with regular milestone accomplishments, and whose success of necessity would involve an entire generation of Americans from childhood to adulthood in the saga of exploration beyond low earth orbit.

4. In the Pathway Principles, the first exploration pathway characteristic is that “The horizon and intermediate destinations have profound scientific, cultural, economic, inspirational, or geopolitical benefits that justify public investment.” NASA is primarily an organization of, and managed by, engineers and scientists. How would you suggest that NASA shape a pathway to have profound cultural, economic or inspirational benefits?

Despite being composed principally of scientists and engineers, NASA does have an understanding of which destinations produce important cultural, economic and other benefits. However, it is not up to NASA alone, or even primarily, to choose a pathway; rather, it will be up to the nation through Congress and the Administration—with the guidance of NASA expertise—to select and pursue a meaningful target.

Appendix II

ADDITIONAL MATERIAL FOR THE RECORD

WRITTEN STATEMENT SUBMITTED BY REPRESENTATIVE DONNA F. EDWARDS

OPENING STATEMENT

Ranking Member Donna Edwards (D-MD)
Subcommittee on Space
Committee on Science, Space, and Technology

Full Committee Hearing
"Pathways to Exploration: A Review of the Future of Human Space Exploration"

June 25, 2014

Good Morning, and welcome to our panel of witnesses. Mr. Chairman, thank you for calling this hearing on the "Pathways to Exploration: A Review of the Future of Human Space Exploration".

While many in this country were not born at the time, history books remind us that almost 52 years ago this September, a young President challenged this country to dare to be great. President Kennedy's famous words, *"We choose to go to the moon in this decade and do the other things, not because they are easy, but because they are hard"* has become part of our Nation's fabric. These words launched NASA onto a path of space exploration and discoveries that few could have foreseen in 1962.

Today, I cannot deny that the world we live in is much different from when President Kennedy spoke at Rice University. Yet, the very basic tenets of why we embarked on that journey to the Moon in 1962 have not changed, regardless of how the world has.

President Kennedy said on that day *"We set sail on this new sea because there is new knowledge to be gained, and new rights to be won, and they must be won and used for the progress of all people"*.

Today, we will hear from the co-chairs of the latest National Academies review of human spaceflight. While some may shrug off this effort as just another in the line of blue ribbon panel reviews, I think they are mistaken. The observations, findings, and recommendations of the panel, ably led by Governor Daniels and Dr. Lunine, lay out a key challenge to us as a country.

The panel is telling us that if we are to have a human space exploration program, then it must be worthy of the considerable cost to the nation and great risk of life. The panel is also telling us that there is no single rationale that is uniquely compelling to justify such investment and risk. Rather, the panel is saying that human space exploration must be done for both pragmatic and aspirational reasons.

I am heartened that the detailed findings and recommendations from the panel mirror many of the key aspects of the NASA Authorization Bill recently passed by the House. Both identify Mars as a goal, the NRC panel calling it *the* horizon goal and both call for a specific sequence of intermediate accomplishments and destinations of increasing difficulty and complexity leading to the goal of a human mission to Mars.

Both recognize that it will be a highly complex and technologically challenging endeavor. And both recognize the risks, such as space radiation, to our astronauts. Having converged on the *what*, the task at hand is determining *how*.

Mr. Chairman, I look forward to hearing from our witnesses, particularly how we can galvanize this great country into making the sustained commitment necessary to enable a human mission to Mars.

Thank you, and I yield back.

